Contribution to the modeling of technology transfer in green IT with multi-agent system

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Contribution to the modeling of technology transfer in Green IT with Multi-Agent System

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RESUME en français

Depuis 5 à 10 ans, les recherches sont nombreuses sur la réduction de l'énergie en l'informatique (principalement sur la réduction de l'électricité). Plusieurs études ont en effet alerté les intervenants et les organismes environnementaux sur l'urgence du problème de la consommation d'énergie des infrastructures à grande échelle, comme les centres de données, l'informatique en nuage ou simplement les sociétés exploitant des serveurs et de nombreux équipements IT.

Cette prise de conscience est passée d'un problème peu important à une contrainte majeure sur le fonctionnement de ces infrastructures. Dans certains cas, les coûts d'exploitation surpassent les coûts d'investissement, et de nouvelles méthodologies sont nécessaires pour réduire les coûts et l'impact écologique. De nouveaux matériels sont développés par les fabricants d'équipements pour diminuer ces coûts. Seules quelques techniques de base sont offertes aux niveaux logiciels et intergiciels, par les éditeurs. Mais dans les laboratoires, certaines techniques ont prouvé leur efficacité sur des données synthétiques, des tâches dédiées ou des applications sélectionnées, pour être en mesure d'économiser de l'énergie au cours de la vie d'une infrastructure, dans plusieurs contexte, depuis le Cloud au HPC. Malheureusement, le transfert (ou même la connaissance de l'existence) de ces techniques aux industries est limité à des partenaires de projets, des entreprises innovantes ou de grands centres de recherche privés, capables d'investir du temps (et donc de l'argent) sur ce sujet.

Dans ma thèse, je m'intéresse sur les raisons de la faible adoption de plusieurs résultats de la recherche, des plus simples aux plus élaborés et je modélise les liens et les interactions entre les acteurs du transfert technologique. Le champ cible a été limité au Green IT (ou informatique éco-responsable), mais la méthodologie et les modèles développés peuvent être étendus à d'autres domaines. L'idée est d'identifier ce qui manque et comment augmenter la vitesse du transfert des connaissances scientifiques.

La méthodologie est basée sur le cheminement suivant: d'abord, identifier les acteurs impliqués dans le processus de transfert technologique, comprendre leurs motivations, leurs moyens d'actions et leurs limites. Après une étude de l'état de l'art dans le domaine de la diffusion de l'innovation et de la gestion de l'innovation, cette phase a consisté à la production et l'analyse d'une enquête dédiée ciblant des chercheurs et des entreprises, de tailles et de chiffre d'affaire différentes, restreinte à ceux qui travaillent dans le Green IT. Identifier chaque acteur ne suffit pas, car ils interagissent, et par conséquent, leurs liens et le potentiel de ces liens pour le transfert technologique ont également été étudiés avec soin dans une deuxième phase afin d'identifier les plus importants, avec la même méthodologie que l'identification des acteurs.

A partir de ces deux phases, un système multi-agents (SMA) a été conçu. A ma connaissance, ce travail est l'un des rares à essayer de modéliser l'interaction complexe des acteurs pour le transfert technologique: Seulement des études limitées (deux acteurs, un seul type d'interaction) existait.

Les agents sélectionnés pour être inclus dans le modèle sont les chercheurs, les centres de recherche, les entreprises, les bureaux de transfert de technologie (BTT) et les organismes de financement. Ces agents évoluent indépendamment et interagissent au sein de partenariats directs et de projets (impliquant plus de 3 acteurs). Les algorithmes de leur évolution et de la construction de projets sont proposés et les principaux paramètres de leur évolution identifiés, avec chaque acteur ayant ses propres objectifs (à savoir les chercheurs ont besoin de publier, les entreprises veulent augmenter leur chiffre d'affaires, etc.).

Une métrique globale est proposée pour relier l'indicateur de performance en matière de durabilité (SPI) du SMA. Il est basé sur le SPI de chaque acteur individuel. Il représente pour chaque acteur ses efforts vers la durabilité, c'est l'agrégation des indicateurs de performance écologiques, économiques et sociétaux. Par exemple, d'une part, l'emploi généré par l'activité de l'acteur est un mouvement positif vers plus de responsabilité sociétale, mais d'autre part elle réduit l'indicateur de l'environnement puisqu'un nouvel équipement IT sera probablement utilisé par les nouveaux employés.

La comparaison de différents comportements des acteurs vers leur objectif individuel est important en utilisant des conditions opérationnelles diverses. Par exemple, changer le montant d'argent que les organismes de financement mettent dans des projets pourrait avoir une influence sur chaque acteur. La modification de la probabilité de succès d'un projet changera le chiffre d'affaires des entreprises qui peuvent investir plus ou moins dans la recherche. Je compare donc le comportement du SMA (à savoir les objectifs des acteurs et les changements SPI globaux) en faisant varier plusieurs paramètres de la simulation: le montant maximal de financement, le taux de conversion d'un projet vers un brevet, l'incitation qu'un centre de recherche peut offrir à ses chercheurs, la présence d'un BTT et sa part sur le résultat des projets. En outre, une proposition est donnée à intégrer les valeurs SPI dans le comportement de chaque acteur, de sorte qu'il ait un comportement plus écologique. L'impact de cette intégration est comparé avec les mêmes paramètres qu'auparavant.

La mise en œuvre du SMA a été développé en utilisant NetLogo, un environnement bien connu de simulation de système multi agent. La polyvalence du modèle développé permet d'étendre son utilisation vers un autre domaine, explorant différents comportements des acteurs impliqués dans le transfert de technologie et, enfin, en ajoutant facilement de nouveaux acteurs de l'innovation (étudié dans le mémoire, mais non inclus dans le modèle).

Enfin, les contributions de cette thèse sont:

- Une étude approfondie de l'interaction complexe des acteurs du transfert technologique dans le domaine du Green IT et de la durabilité
- Une transposition du modèle en algorithmes pour les comportements des acteurs et leurs évolutions au cours du temps
- Un outil développé qui peut être testé sur plusieurs paramètres, ce qui permet, par exemple, à un organisme de financement de comprendre l'impact de sa décision (montant consacré au projet, le taux de financement, etc.), ou à une société de l'impact de participer à des projets ou collaborations directes (montant consacré à la recherche, les efforts pour convertir le projet aux produits réels, etc.).

Abstract

Over the past 5 to 10 years, research is numerous on energy reduction in IT (mainly electricity reduction). Several studies indeed alerted the stakeholders and environmental agencies on the urgency of the problem of the energy consumption of large scale infrastructures, like data centres, clouds or simply companies running servers and lots of IT equipment.

This awareness moved from a non-so-important issue to major constraints on the operation of these infrastructures. In some cases, the operational costs reach the investment costs, urging new methodologies to appear in order to reduce costs and ecological impact. As of today, new hardware are developed by equipment manufacturers to decrease these costs. Only few and basic techniques are offered at the software and middleware levels out-of-the-box: But in laboratories, some techniques have proven on synthetic data, dedicated workflows or selected applications, to be able to save energy during the lifetime of an infrastructure, in several contexts, from Cloud to HPC in particular. Unfortunately, the transfer (or even the knowledge of the existence) of these techniques to industries is limited to project partners, innovative companies or large private research centres, able to invest time (thus money) on this topic.

In my thesis, I investigate the reasons restraining the large adoption of several research results, from the simpler ones to more elaborated ones and I model the ties and interactions between the actors of the technological transfer. The target field has been restricted to Green IT but the methodology and the developed models can be extended to other domains as well. The idea is to identify, on the scale of technical maturity for wider adoption, what is missing and how to increase the speed of the transfer of scientific knowledge.

The methodology is based on the following path: First, identifying the actors involved in the process of technology transfer, and understanding their motivations, their means of actions and their limitations. After a study of the state of the art in the domain of innovation diffusion and innovation management, this phase involved the production and the analysis of a dedicated survey targeting researchers and companies, from different size and turnover, restricted to those working in the Green IT field. Identifying each actor is not sufficient since they all interact; therefore their links and the potential of these links for technology transfer have also been studied carefully in a second phase so as to identify the most important ones, with the same methodology with the actors' identification.

From these two phases, a multi-agent system (MAS) has been designed. To the best of my knowledge, this work is one of the few trying to model the complex interplay of actors for technological transfer: Only limited study (one two actors, only one interaction type) existed.

The selected agents to be included in the model are the researchers, the research facilities, the companies, the technology transfer offices (TTO) and the funding agencies. These agents evolve independently and interact within direct partnerships (one to one) and projects (involving more than 3 actors). The algorithms of their evolution and project constructions are proposed and the main parameters of their evolution identified, with each actor having its own objectives (i.e. researchers need to publish, companies want to increase their turnover, etc).

A global metric is proposed for relating the sustainability performance indicator (SPI) of the MAS. It is based on the SPI of each individual actor. It accounts for each actor for its efforts towards sustainability, aggregating ecological, economic and societal performance

indicators. For instance, on the one hand the employment generated by the actor activity is a positive movement towards more societal responsibility, but on the other hand it reduces the environmental indicator since more IT will probably been used by new employers.

Comparing different behaviours of actors towards individual objective is important using diverse operational conditions. For instance, changing the amount of money the funding agencies will put in projects might have an influence on each actor objective. Changing the project success probability will also change the turnover of companies that may invest more or less in research. I compare therefore the MAS behaviour (i.e. the actors objectives and the global SPI changes) by varying several parameters of the simulation: the maximum amount of funding, the conversion rate from a project to a patent, the incentive one research facility can offer to its researchers, the presence of a TTO and its take on the projects outcome. Additionally, a proposal is given to integrate the SPI values in the behaviour of each actor, so that it has a greener behaviour. The impact of this integration is compared for all the same parameters as before.

The implementation of the multi-agent-system has been developed using NetLogo, a well-known multi-agent-system simulation environment. The versatility of the developed model allows for extending its usage towards other field, exploring different behaviours of actors involved in technology transfer and finally adding easily new actors of innovations, studied in the dissertation but not included in the model.

Finally, the contributions of this dissertation are:

- A thorough study of the complex interplay of actors of technological transfer in the domain of Green IT and sustainability
- A dedicated model transposing to algorithms the behaviours of actors and their evolutions along time
- A developed tool that can be challenged against several parameters changes, allowing, for instance, a funding agency to understand the impact of its decision (amount dedicated to project, rate of funding, etc.), or a company the impact of participating in projects or direct collaborations (amount dedicated to research, efforts to convert the project to actual products, etc.).

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Chapter 1. Introduction

« Scissors cuts paper, paper covers rock, rock crushes lizard, lizard poisons Spock, Spock smashes scissors, scissors decapitates lizard, lizard eats paper, paper disproves Spock, Spock vaporizes rock, and as it always has, rock crushes scissors. » Sheldon Cooper, B.S., M.S., M.A., Ph.D., Sc.D.

1.1. Introduction and Problem

Information Technologies (IT) has been demonstrated along the recent years to be a major contributor of energy consumption and CO2 emissions, in particular with the Cloud computing development and the tremendous raise of data centres in the world [1].

Global energy consumption increases at a higher rate than the total energy production, in a process called electrification of the energy system. Electricity consumption per capita more than doubled from 1974 to 2011. Its overall share of total energy demand has risen from 9% in the 1970's to over 17% (20,460 TWh), and it is expected to increase even more in the next years [2].

Energy demands of information and communication technology (ICT) sector including end-user devices as computers and smart phones, as well as network equipment as modems, routers and network infrastructures is on the increase. ICT accounted for 2% of total final global electricity consumption in 2007 [3], more than 8% in 2013 [2], and it is predicted to consume up to 14.5% in 2020 [4]. Considering only data centres, their share reached 0.5% in 2000, 1% in 2005 and 1.68% in 2013 [5] [2], following a linear increase trend.

Additionally, edge devices and user premise network equipment as the aggregate of electronics located in private households and offices, constitute 3.36% of final global electricity consumption. Despite the advent of more energy efficient personal computers (PCs), which includes desktop computers and laptops, their electricity demand increased more than 5% from 2007 to 2012, during the same period, data centres' demand increased around 4.4% [6].

During the last years several standards bodies like ISO (International Organization for Standardization), ETSI (European Telecommunication Standard Institute) have been created both internationally and at a government level. These groups are not always only related to IT but there is a level of cooperation between different bodies and there appears to be progress in the international standardization in the sector of IT, Green IT, and data centres.

Intuitively, "Green IT" refers to the process of reducing the environmental impact of IT. It brings awareness, knowledge and adoption of environmentally sustainable practices, policies and technologies. It is a process required for energy consumption reduction and sustainable development. Green IT and its software, hardware and usage consume energy, but once established, it helps to reduce energy consumption in technical areas and additionally in almost every part of life. Green IT might be therefore considered as another burden for our environment or as quite a recent – compared to other – research topic within society and industrial life as well as within the research community.

Green IT is a factor of innovation, and can be considered as a potentially large impacting contributor in terms of employment and societal improvements. If we all contribute to this development it will make our planet greener and more sustainable for future generations.

Green IT is explored by a large set of academic and industrial research groups through the world. To be more influential, it requires formalized links and support from several bodies (funding agencies, standardization bodies, Technology Transfer Offices…). It is crucial to understand the interactions between these entities in order to improve Green IT adoption and advancements.

While the diffusion of innovation has been studied in the literature mainly from the marketing point of view, I decided to explore it from the perspectives of its impact on the society globally and not only towards a given set of target users. I am interested in the development of innovation or technologies, and in the transfer of this towards other actors, to finally benefit to all.

The research question of this work can be stated as: What are the main drivers for improving technology transfer in Green IT? Is it possible to model these drivers?

1.2. Motivation

The motivation of this work comes from the experience I gained during my years as project manager in different research institutes, together with my active participation in a European funded project under the EU FP7 umbrella: CoolEmAll. During these years I realized that the role of each actor of innovation was not completely understood, neither from the point of view of the researchers, nor from the companies nor funding agencies, among others. As an example, the CoolEmAll project raised 2.6 million euros funding, distributed among 6 partners (4 research institutes, 2 companies): CoolEmAll was an FP7 project that aimed at providing advanced planning and optimization tools for modular data centre environments. The project developed a suite of tools to optimize the construction and the operation of datacentres. The researchers worked hard, nice publications were done, a prototype of hardware and a simulation toolkit were developed. A market assessment was done, and the project well publicized among potential users. The project was successful in the sense that it reached its objectives. But in the end was the impact for Green IT positive, and if so, to what extent? The end of the project was reached, the consortium broke up, and a timid try for marketing the solutions was started but without reaching the market. Could the outcome have been better?

When deciding to join a consortium, to start a new project, to fund a new field of research, the involved deciders lacked tools to study the impact of their decisions. From the point of view of funding agencies, it is even clearer: Should a budget of 10 or 100 million euros should be put on that topic to make a real impact at the end on the society at large? Is 10 million sufficient and is the extra research and impact given by the 90 additional millions worth it? And in the domain of Green IT in particular, what is the impact on tangible indicators of sustainability?

It is unrealistic to believe that one model fits all, but we believe the field of Green IT is young and small enough to study the different aspects of the technology transfer. This thesis tries to propose a first step towards providing decision tools by studying the impact of their decisions (e.g. amount to fund, staff to commit to a project, etc.) on the global objective of making IT greener.

1.3. Methodology

The methodology I adopted during this work is the following: First, identifying the actors of technology transfer, and analysing their motivations. This was done through literature review, personal interviews and an online questionnaire. Second, understanding the links (or potential links) between the identified actors and their impact on the development of Green IT was studied. This allowed us to focus on some actors and to let some aside for this dissertation. Finally, to better understand, the complexity of the technology transfer system needs to be modelled, and we decided to adopt a Multi Agent System (MAS) based approach for this. Using MAS has the advantage to focus on the behaviour of each individual actor and to let a global behaviour emerge, which is especially useful in the context when too many actors with so many different motivations interplay.

1.4. Outline

The rest of this dissertation document is organized in the following way:

Chapter 2 defines Green IT in the context of our work. It analyses the results of a dedicated online survey, in order to get some insights on the development of the technology transfer. It introduces the actors of innovations (standardization bodies, influential groups, funding agencies, universities and academic research institutes, companies, technology transfer offices, business angels) in a standardized canvas which consists in defining the actor, giving some illustrative examples, analysing the leverages for Green IT development and focusing on the potential boosting or slowing down features. The main actors are identified together with their motivations (and the differences between them).

- Chapter 3 explores the links between actors, from informal to formal ones. From the potential high number of interactions, the most pertinent ones are analysed in detail to understand their impact on the technology transfer. Finally, we selected researchers, research facilities, companies and technology transfer offices in order to integrate these in the first version of the model, for this dissertation.

- In chapter 4, after a literature review dedicated to complex problem modelling and multi agent systems in the context of innovation diffusion, I propose a multi-agent-system integrating the previously selected actors and their links. Developed in NetLogo, the system evolves during a period of time where the impact of global parameters (such as the presence of TTO, the amount of money dedicated to research, the research-to-patent rate, etc.) can be stored and analysed. The versatility of the multi-agent system makes it useful in cases other than the field of Green IT.

- Chapter 5 is dedicated to analysing the performance and behaviour of the MAS. It introduces a sustainability performance indicator (SPI) and proposes to analyse the impact of the previous selected parameters from this perspective. Also, I propose in this chapter a modification of the behaviour of the actors who take into account more Green-related decisions, and to study their impact on this SPI.

- Chapter 6 concludes the dissertation and gives perspectives of this work. In particular, it selects the most interesting parameters to further analyse and explore the extension of the model.

Chapter 2. Actors of innovation in Green IT

In this chapter I introduce the various drivers in Green IT. After starting by defining Green IT in terms of ecological, economic and societal aspects, I present a survey analysis that was produced during my PhD. This survey helped us to define the relevant actors of technology transfer in the domain of Green IT. Their main characteristics are defined and the difference in their approaches to Green IT is analysed. This chapter continues with different kinds of cooperation the actors can set up.

2.1. Definition of Green IT

Numerous definitions of Green IT have been proposed in the scientific and public press. Each of these definitions is taking different aspects into account and is more or less general. Some of them are focused on server centres, some will include the screens, the printers, the IP phones while others will concentrate on the core computers. Some will limit their definition to the usage of IT and energy management some will include economic thoughts as well.

Already, Lorenz Hilty [7] has given a definition of the life cycle. There is the use phase, the production, and the end of life. Green IT can apply to every phase, decreasing the ecological damages. In this definition of Green IT, the real costs for production are missing. Real costs, hence operating costs are very difficult to associate with one product. They include fixed and variable costs. Fixed costs stay the same regardless the number of products (e.g. overhead); variable costs can vary according to the number of products produced (e.g. material). To include real costs in a life cycle each single product would have to be studied, therefore a simplification is suitable in order to raise awareness.

Also the “costs” for the environment, which we all have to pay, are not taken into account, e.g. the water consumption for raw material production. These costs will be paid – in reality – only by the producing countries, requiring us to take a closer look at the people producing servers/components and the people living in these areas.

San Murugesan defines in [8] the field of green computing, which might be seen as Green IT, as "the study and practice of designing, manufacturing, using, and disposing of computers, servers, and associated subsystems — such as monitors, printers, storage devices, and networking and communications systems — efficiently and effectively with minimal or no impact on the environment”.

Green by IT (also: Green through IT) covers the support of sustainable development by means of ICT. This includes for example software that reduces environmental problems through optimization. Green IT (also: Green in IT) denotes actions through which ICT itself could become more sustainable. This concerns hardware and software, where the hardware part is common knowledge. [9]

In [10] Esfahani proposes a literature review on Green IT and Green Information Systems (Green IS). He noted that “Information technologies can affect the natural environment through two broad categories named as first order and second order effects [11]. The first order refers to the negative impact of IT production, use, and disposal on the environment. This perspective considers IT as part of the problem [11], [12]. So, making IT production, use, and disposal more environmental friendly and greener is referred to as Green IT [12], [11], [13], [13]. The second order effect refers to the positive impact of IT on the environment, which considers IT as part of the solution. Hence, utilizing IT to make business processes and activities greener is known as IT for green or Green IT ». [14], [12], [15], [16].

The term Green IT “denotes all activities and efforts incorporating ecologically-friendly technologies and processes into the entire lifecycle of information and communication technology” [17].

Green computing or Green ICT refers to environmentally sustainable computing or ICT. A holistic view, greening ICT is not just about reducing direct power consumption. [11]

All the definitions are representing various ideas about Green IT and one reason might be that IT is in general a rather young topic, and Green IT is even younger. 50 years ago the number of information technologies was that low that the impact on the environment was insignificant. The impact of IT on the environment during the last 5 decades increased due to the growth of IT related devices. The interests of providers and the demand of users are changing dynamically and accordingly. Taking the example of the rising electricity costs, it is obvious that companies understood this impact and started setting up counter measures. These measures addressed energy reduction to reduce costs. This action - together with other actions related to the reduction of energy consumption in the field of IT- , were summed up under the name of Green IT. In the last years, more companies, citizens, and governments were considering Green IT leading to the fact that there is no final definition of Green IT under such changing interests. Following the work of others, I believe that three main reasons drive the interests for Green IT and its development: ecology, economy, and society.

2.1.1. Ecological reasons

The first associated reasons for the usage of Green IT are ecological reasons. The following reasons do not only apply in IT but also in other areas and lead users and producers to an ecological awareness. Carbon dioxide emission is boosting the natural greenhouse effect causing the global warming. The worldwide estimated emission of carbon dioxide caused by IT is 600 million tons, still expected to grow up to 60% more in 2020 [18]. This is due to the high consumption of energy during the lifetime of the information technology.

The production of information technologies is polluting the environment. Many computers are produced in countries under inadequate ecological conditions. According to [7] the ecological damage through a production of a computer in China is almost the same than the ecological damage of the use of a computer during 6 years in Switzerland, as can be seen from Figure 1.

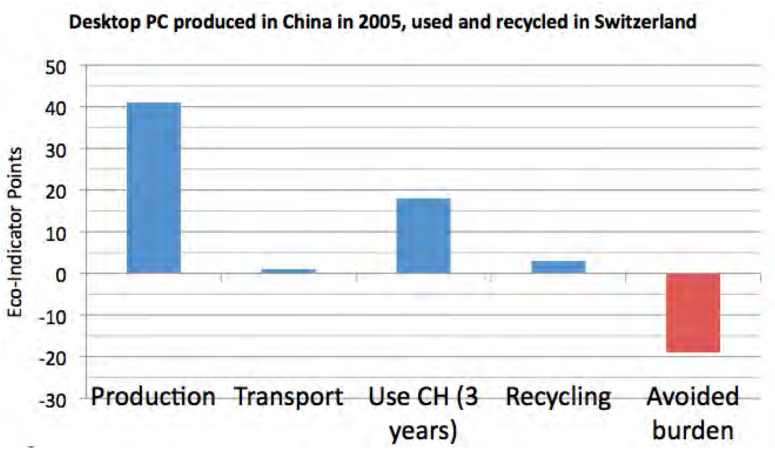


Figure 1: Comparing production, transport, usage, recycling and loss for a typical PC Desktop, modified from [18]

In information technology there are 3 stages of the life cycle: Ecological pollution during the production has the highest impact. Rare metals like Indium are used for the production of information technologies. Not to reuse these metals means that the resources will soon be exhausted and not available for future generations and nor future technologies. These productions mark the ecological damages, but also for workers and residents around production centres. Green IT cares that these metals are used efficiently, and that there will be no lack in the future, and that reduce the damage to the environment.

The usage-phase pollutes the environment less than does the production phase. As there are a lot of circumstances to be taken into account (cooling, load, individual usage, and others) to calculate the pollution, only a general approach can be given. An approach is to take the technical references of the different hardware producers. There you find information about the consumption of energy. But again, pollution varies according to different factors (real usage, but also temperature of operation, environment of operation, in particular its cooling technologies) and therefore it is almost impossible to verify the provided data as well as the individual pollution. Only a careful monitoring of the on-site equipment will allow for giving the usage-phase pollution amount.

Often undervalued is the e-waste. The U.S. Environmental Protection Agency (EPA) declared that Americans throw out more than 3 million tons of consumer electronics in 2012 [110]. This makes electronic waste one of the fastest growing components of the municipal waste stream. In the European Union (EU) the disposal of e-waste is regulated with guidance like the WEEE guideline (Waste Electrical and Electronic Equipment). Unfortunately, this rule is bypassed because of financial reasons and e-waste is sometimes transported to the developing world. There the waste is recycled in a very primitive way leading to a contamination which impacts humans and the environment. Green IT can identify these aspects and should insist that recycling is done in a « green way ».

2.1.2. Economic reasons

Companies invest annually a big amount of money in information technologies. But their infrastructures, memories, storage and computing power and capacity are not well utilized.

Let's take an example: Already the cooling is an important factor with a lot of potential economic saving. A lot of companies run their data centre – if it is an in-house service – too cold. Already increasing the temperature for about 2 degrees Celsius in existing data centres would save a lot of energy, since the link between temperature and the power needed to reach that temperature is not linear. The ASHRAE Technical Committee 9.9 is regularly producing recommendations on the possible thermal limits for operating a data centre ("Thermal Guidelines for Data Processing Environments", last in 2011) [19]. In the last years, improvements from IT hardware companies on their silicon equipment allowed these thermal recommendations to increase regularly. In 2008, the ASHRAE move from 25°C to 27°C as the upper limit for common equipment, and even up to 40°C to 45°C for newer equipment, a new recommendation from the 2011 report. With every 1°C increase, between 2 and 5% less cost in cooling is witnessed [20] [21]. Some data centres are even run with free-cooling: The air at ambient temperature from outside is used to remove the heat from the servers. Intel in New Mexico ran servers at 33°C for 10 months, and they estimated a decrease of costs up to 67%, i.e. an annual savings of $2.87 million in a 10MW data centre [22].

Additionally the workload is not measured but often only estimated and this leads to the problem of an oversized infrastructure. If the data storage is outsourced companies pay too much for this service, as they are not aware of the real workload, so in general companies rent too much space for their IT. In both cases a better operating grade, more efficiency, a monitoring of the workload as well as company policies may help to reduce costs.

Step by step Green IT knowledge was and is discovered and "transported" to companies. Often a Green IT expert would find cheaper and "greener" solutions in caring for more efficient usage of older equipment and a higher workload of new technologies. But companies do not always use these solutions, as some investments have to be done first, or the hierarchies take time to decide or (technical) staff has to be convinced. However investors might be more attracted by companies caring for Green IT. This leads to increased company wealth, which in turns allows the company to invest in new technologies or processes.

Finally there are some legal incentives to encourage companies in saving energy, investing in greener IT, or supporting research in the field of Green IT. These initiatives might come from local or regional governments or funding organisations. In Australia for instance, a carbon-tax for the top emitters (among which data centres) has been voted, leading obviously the emitters to optimise their operations, or turn to sustainable data centres [23].

Even if the price for energy might be lower in the future due to new technologies used for energy production, there are still resources consumed, and the environment is polluted. Energy saving is not only saving money, but also saving our planet for the next generations. This situation is unlikely to happen because during the last years the price for electricity rose continuously and in my opinion is going to rise in the future as energy production is expensive, using resources and polluting the environment. New technologies are developed but still their usage is limited due to costs of production, limits of resources and space [24].

2.1.3. Social reasons

Green IT has also a social aspect since each government (should) aims at preserving the environment and serving the country and its inhabitants. "Green" behaviour was becoming a movement within the society, and companies working environmental friendly have a higher prestige than the ones paying less attention to the environment. This positive image reflects also on the applications of job seekers. Working for an innovative, green company stimulates people. These employees are proud on their and the company's environmental engagement, the company gets free publicity when these employees talk in their everyday life about this. Some new clients may contact the company, better-qualified candidates may apply for opened positions and there might be an advantage in comparison with the competitors if you answer to a call of tender. Even if social reasons are not the main incentives for Green IT, there is an impact.

2.1.4. Our definition of Green IT

Based on different definitions and motivations, a definition of Green IT is stated, which is for now the basis for this work. “Green IT is the environmental and resource saving effort in the IT. The reason for using Green IT may arise from economic or ecological interests. Actions can affect on the whole lifecycle of information technology - meaning from the construction via utilisation through disposal.”

Green IT is therefore a movement toward sustainability. As shown in Figure 2, sustainability is at the cross between ecological, economic and social aspects.

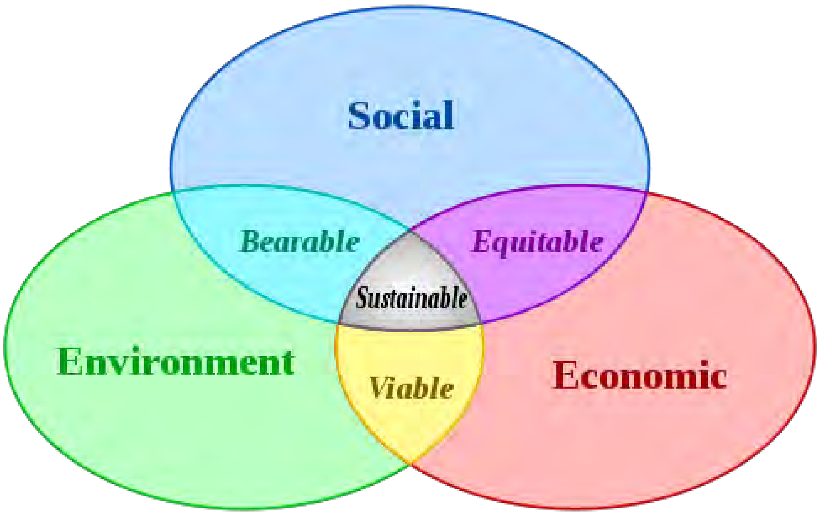


Figure 2: The place for Sustainability (picture from Wikipedia), built from [25].

Let’s analyse Green IT within respect to this definition and its role for sustainability. In best cases Green IT is sustainable: Green IT is in the central “sustainable”-area and stays there whatever are the operations on the system. For instance, buying not too much expensive hardware leads to a movement away from sustainability: Indeed, from the economic point of view, a purchase is done, and from the ecological point of view, this new hardware had to be produced. But this can be compensated when this new hardware is consuming less electricity. It should be noted that making no efforts will lead the IT to move away of the sustainability area due to the obsolescence of the equipment.

In the general case, Green IT will be represented as a direction towards the central area. For instance, calculating the price of the products including the financial costs for the e-waste before renewing equipment will move, within the social point of view, towards sustainability.

In the worst case, Green IT is unfortunately leaving away from the sustainable-area to a border area, and it is not important towards which direction the movement is done. For instance a company can buy new hardware which consumes more electricity than the older ones, but still consumes the minimum maximum (instead of minimum) electricity from the market, for the needed computing power. In that example, the movements in the environment and the economic directions are clearly not towards sustainability. But this company can still advertise some Green IT efforts.

Green IT is always moving as there is always a development in one of these directions. Depending on the direction and how far it is moving to or from the sustainable area, it is possible to say if there is still a part of Green IT in it or not. With this view it is possible to give a first label of Green IT. All known components will be filled, and as a result you have an indication if you can still name it Green IT or not. After developing some standards/limits for Green IT, for Economic, Environment and Social we can categorise a special innovation, meaning a movement within the Green IT; even giving marks to them according to their usefulness to Green IT.

In chapter 4 we will propose a metric based on the evolution of different factors that will help decide the direction of the Green IT factor, towards sustainability or not, and to compare diverse scenarios.

2.2. Survey analysis

In order to start the understanding of the complex interrelationships between the actors of innovation transfer in the Green IT field, we conducted a survey among a population of research facilities, service providers and company members. We identified arbitrarily initially these populations as the main drivers of innovation in Green IT that we had an easy access to.

For the survey, the following definitions were given to respondents:

- Research facility: A centre where research is done, not including centres within a company
- Company: is defined as an artificial person, invisible, intangible, created by or under law, with a discrete legal entity, perpetual succession and a common seal
- Service provider: TTO (Technology Transfer Office), Internet Service, Provider, any company associated with a research facility, which is financially not related to an institution.

The survey was built of 28 sections with in total 158 questions. More than 80 participants mainly from Europe had to answer to common questions (as their affiliation, percentage of finished Green-IT project, etc.). Depending on the affiliation of the participant different adapted questions were to answer as for each group of participants different parameters were examined.

The participants were in majority well-known in the Green IT community. The survey was done anonymous as otherwise no real feedback might have been provided. As a result no exact numbers can be provided concerning the participation of Green-IT specialists. The link to the server was distributed via email and participants had the possibility to answer within 1 month.

The questionnaire can be grouped in 4 sections:

- General questions about the participant, its affiliation (research facility or company), the structure of its affiliation, as well as the main field of its activity and the one of its affiliation.

- Questions about the IT structure and its relative greenness (including outsourcing)
- Questions about the decision process for moving to Green IT: when, who, why, what?
- Questions about Green IT projects and cooperation (funding, beginning, runtime, results and products, presentations, success and gain).

The answers to the questionnaire were analysed with SPSS software, version 21. This allowed making a strong statistically sound analysis of the answers.

In the following sections we will not detail all questions and answers, but we will choose to highlight the questions and answers with a significant difference in percentage and with a similar percentage of answers given by companies and research facilities. Additionally the different answers to multiple choice questions are analysed in order to find important topics that will serve for the next steps of the work. These choices illustrate the main drivers of innovations in the field of Green IT and will help to define the actors and their interests (see next Section 2.3) as well as a formal model used in Chapter 4 and 5.

The full questionnaire and its results can be found in Annex 1 and Annex 2 of this dissertation.

2.2.1. Share of Green IT Projects

A project is a planned piece of work that has a particular aim, especially one that is organised by a government, company, or other organisation with a limited funding and with more than two partners. The share of Green IT projects represents the ratio of projects contributing to Green IT among all projects of each survey participant. It is not specified if this has to be a direct or indirect link, meaning the project contributes directly to a Green-IT project (being a partner) or indirectly, as Green-IT is a minor part within the project (the result may be used also in Green-IT).

From the survey, it can be seen that 25 % of the projects done in companies and 30% of the projects done in research facilities have a link (direct or indirect) with Green IT. These quite high percentages are biased by the fact that most of the participants are related to Green IT. However, it exhibits that even for this selected population, Green IT is not their only possible projects funding.

The lower percentage of participations of companies in Green IT projects might be the result of the different funding for companies compared to research facilities. Another reason is the approach difference between companies and research facilities: Companies are profit orientated, need an immediate outcome or at least have to see the added value to the company, which may not be immediate for companies. In research projects funded by the EU or at the national level, there is obviously in general no immediate return on investment (ROI) and the outcome of a project with a runtime of two to three years is not certain, as well as the usage of the result/product has to be defined in negotiations between partners. Research facilities look for an exchange of knowledge, therefore an extension of competences. Their responsibility is common welfare and they have a general approach to innovation. The funding may cover 100% if the costs for the permanent staff are not taken into account, as anyway these are costs from the research facility.

2.2.2. Share of Green IT Cooperation

Cooperation is an act or instance of working or acting together for a common purpose or benefit. The two partners do not receive funding from a third party but there might be a financial flow. Note that it is not compulsory. The share of Green IT cooperation represents the ratio of projects contributing to Green IT among all cooperation of each survey participant. As for Green IT projects, it is also not specified if the Green IT cooperation has an indirect or direct link to Green IT.

The share of Green IT cooperation is 36 % in companies and 23 % in research facilities. The approach (decide and act) to innovation of companies is more adapted to this partnership. As cooperation is only between two parties a contract can be agreed and the action may start right after. The outcome is clearly stated and – in general – there is no financial risk concerning the usage of the result/product, the payment is done accordingly to the progress of the cooperation. From a company perspective, it follows a more classical subcontracting process and can be managed with a dedicated management process (clear objectives from the very beginning, monitoring progress, quantifiable deliverables, software developments agreements and receptions).

The structure of research facilities is based for long-term relations with a long-term funding, as there is research and formation combined. As companies are – in general – not supporting an idea of an engagement for a long period as they are expecting results quickly, a public funding is totally adapted for research facilities. As a conclusion research facilities are less interested in short time cooperation, and put more efforts, human resources in projects than in direct cooperation. In a cooperation with companies, researchers in IT fear to be used as engineering support without clearly seeing the advances in research in that kind of cooperation. On the opposite, direct cooperation between researchers are more common than cooperation between researchers and companies.

2.2.3. Which new hypes in Green IT caused a change of direction or policies?

2.2.3.1. Greenwashing

Greenwashing is the practice of making a misleading claim about the environmental benefits of a product, service, technology or company practice. Greenwashing can make a group appear to be more environmental-friendly.

The survey gave an interesting almost equal result for both companies and research facilities: 29% of companies and 31% of research facilities responded in the survey that the idea of Greenwashing changed the direction or policy. Research facilities have in mind the common welfare while companies are focused on their benefit. Greenwashing is a way of making benefit in form of higher stock price, more customers or favoured partnerships with green organisations. Research facilities may change their focus of interest in order to discover such mismanagement and to become a control unit or supervisory authority.

Even if these reasons for changing are different it is a surprise that research facilities and companies were touched by this hype almost with the same percentage.

2.2.3.2. Economic Incentives

Economic incentives are something, often money or a prize, offered to someone (an individual person as well as institutions) behave in a particular way.

58% of companies declared that economic incentives influenced their behaviour concerning projects, cooperation or policies. For companies, this percentage is surprising quite low as far as companies are profit orientated. Henceforth the legislative authorities have to think about new ways to attract companies with economic incentives.

For 66% of research facilities economic incentives was the reason for a change. Given the difficulty in research funding in Europe, money tends to be scarce and the financial resources limited: Any subject can give an opportunity for funding, including Green IT.

2.2.3.3. Social Incentives

Social incentive means that the behaviour or actions from companies and research facilities are motivated by the desire to conform to what others (society) do.

While only 36% of companies were influenced by social incentives 54% of research facilities were pointing out that social incentives had an influence in changing the direction of projects, cooperation or policies.

These numbers reflect that obviously research facilities have more freedom of choice, suggested by social incentives (for instance the global policy of the research facility towards Green IT) and the one limit is the available budget. While companies have to respect a company policy and due to a decision making process with several hierarchy levels the freedom of action of each individual is limited.

2.2.4. What were the main actions taken to adapt to this hype?

New technology always means new business opportunities and new research. Having a look on the reaction to new technology, new ideas on the common market the survey proposed three solutions as an reaction: to hire more staff, to invest in IT, to look for new partners.

In the following table, mean values are given, where a value of 1 means “never” and 6 means “multiple times per year”.

	Companies	Research facilities
Hired new staff	4,6	1,7
Invested in IT	5,4	1,3
Looking for new partners	3,9	2,4

Table 1: Reactions to new technologies

In total the reactions to new technology is very different from the perspectives of companies or research facilities. Research facilities do not hire nor invest, while companies tend to react more quickly, hire new staff, invest in IT and look for new partners: This shows the limited resources in research facilities that rely on existing structures. However, research facilities tend to look for new partner as companies do, in order to get new projects, cooperation so as to be able to follow the hype.

2.2.5. Who gave the input for this change of direction?

Input is defined as something put into a system to achieve output or a result. The survey asked the participants about the incentive that made them move towards the direction of Green IT. The following table shows the percentage of answers for each group and each possibility.

	Company	Research facility
A research partner	28,6	48,1
An institution/company	42,9	40,4
A superior	39,3	25,0
Myself	64,3	67,3
Legal enforcement	14,3	28,8
Customers/Users	50,0	28,8

Table 2: Incentive to move towards Green IT

For research facilities 48% state that the input came from research partners. It might be argued that this percentage might be obvious as there is a strong knowledge exchange between different research facilities. Research partners influenced only 29% of the companies' changes, while 50% of changes were initiated by customers/clients. From this perspective, it is obvious that the knowledge transfer from research facilities towards companies and the exchange between these different organisations has to be optimised.

A high percentage of answers (more than 64%), either in companies and research facilities, exhibit the personal involvement of the participant: This was expected from the population studied.

Finally it has to be highlighted that only 14% respectively 29% of the changes were started by legal enforcements. In Green IT, recommendations are still more common than legal restrictions.

2.2.6. Which support structures exist that could provide support with building and maintain a cooperation or project?

A support structure serves to support cooperation and projects. The aim of this question was to identify if the presence of a support structure helps or not. The following table displays percentage of answers, for given support departments.

	Company	Research facility
Administrative Support	78,6	71,2
Financial Department	71,4	65,4
IT Department	82,1	69,2
Legal Department	67,9	65,4

Table 3: Impact of the presence of a support structure

In contrast to what is commonly believed research facilities and companies have the same support structure. The biggest difference between companies and research facilities is in the existence of IT departments, 82% for companies and 69% for research facilities. This is due to the targeted audience by this survey: People working in (Green) IT. Therefore there is less need for any IT department in comparison with other departments, where people have less knowledge about IT and support is needed to solve already basic IT problems. Altogether, this criteria is not be differentiating the two groups of participants, although their presence is acknowledged by all.

2.2.7. Is support actually provided from these structures?

Support means practical help provided by departments for participants in projects and cooperation. In this question, the point was to figure out if this presence helps: Existing supporting departments are already important but more important is if real support is provided. The table shows percentage of answers for given support departments.

	Company	Research facility
Administrative Support	64,3	75,0
Financial Department	57,1	69,2
IT Department	60,7	76,9
Legal Department	46,4	67,3

Table 4: Presence of a support structure

In contrast to the common opinion in all categories there is more service provided in research facilities than in companies. This is especially surprising as one of the main arguments of a missing exchange, knowledge transfer between companies and research facilities, is often the arguable point that at research facilities the supporting infrastructure is missing.

2.2.8. How does a new project or cooperation usually start?

A project may start in different ways and here is a comparison of the most effective ways to start a project. The following table shows percentage of answer for each possibility.

	Company	Research facility
Social Media Platform (Facebook, Google+, …	14,3	7,7
Social Networking Platform (LinkedIn, Xing, …)	21,4	11,5
Event like proposer's day	42,9	36,5
Event like a conference, forum, seminar	46,4	50,0
Start-up centre	28,6	21,2
Follow-up of an existing project	67,9	71,2
Personal Relationship	82,1	84,6
Email or Phone without preceding personal contact	42,9	30,8

Table 5: Effective way to start of a project

Besides having personal relationship (more than 80% in both groups), a follow-up project and the participation in conferences and seminars are the best ways of starting projects. Rather surprising is that new social medias like LinkedIn and Google+ are not that efficient.

A start-up centre helps start-ups accelerate their growth with an excellent combination of commercial, technical and design know-how. They also promote the innovation transfer from researchers and help them build actually start-ups. These start-up centres are in close contact with companies and research facilities and therefore the perfect place to start projects and to have an exchange. As these centres are rather young compared to other means (conferences, seminars, ...) it is expected in the upcoming years the corresponding percentage to raise.

2.2.9. Are the results/products created by your project or cooperation usually used and/or sold after the cooperation or cooperation is finished?

A result is in this study defined as a piece of information that is obtained by examining, studying or calculating something.

A product is defined as a commercially distributed good that is tangible personal property, output or result of a fabrication, manufacturing, or a production process, and passes through a distribution channel before being consumed or used.

The following table summarises the answers in terms of percentage.

	Companies	Research facilities
Results are used in-house	67,9	69,2
Results are used elsewhere	64,3	55,8
Results are sold	42,9	30,8
Results are developed further	67,9	73,1
Products are used in-house	64,3	63,5
Products are used elsewhere	64,3	50,0
Products are sold	42,9	26,9
Products are developed further	71,4	63,5
Results are considered green	57,1	53,8
Products are considered green	50,0	50,0

Table 6: Results/Products continuity

Even if in research facilities administrative and legal support is provided there are less results/products sold at the end of the project than in companies. This result may change in the next upcoming years as TTO (Technology Transfers Offices) are built up with the aim to have more patents in the future.

2.3. Definition of existing actors and their objectives

In this section, we define the actors of innovation we consider and their main attributes and the way they can influence the system. For this, we base on previous works [26], [27] where definition of Green IT and main actors are identified and their differences in terms of motivation, approaches, and constraints carefully analysed. It can be noted that each of these aspects can easily be turned into variables and probabilistic laws describing their behaviour.

While the research facilities and companies are the more numerous and constitutes the core of the development of innovation, some fewer actors (typically a factor 1 to 100 or more) must not be forgotten since they have a direct or indirect role in the development of innovation in Green IT.

As in any other technical or scientific field, many actors are involved in the development and adoption of Green IT. These actors are diverse by nature, by interest and motivation and by means of changing the field. They span from single persons (e.g. an activist, a researcher, a consultant), research groups in research facilities (research institutes, universities, academic research networks), companies (developing technologies, advising companies), groups of companies (influential and lobbying groups), governments (through public incentives, laws), groups of governments (e.g. European Union).

All the actors interact in a kind of microcosm building and feeding each other, influencing and moving forward towards Green IT, at least towards their own view on Green IT. The following actors may boost or slow down the development of innovation in Green IT depending on different factors.

Formally, in this section we will detail some of the actors involved in the development of innovation in Green IT. The methodology we pursue is the following: For each actor, we first define it, give some examples and name the action leverages this actor can have in developing Green IT. We outline the boost this actor is giving to the field, or, conversely, the slow down it may provoke.

In [27] we studied the similarities and difference between research facility and industry related to 13 dimensions grouped in 3 categories: the process of research and innovation; the criteria of success and the dissemination aspects; the organization. This section can therefore be seen as an extension of this preliminary work.

2.3.1. Research Facilities

a – Definition: Research facilities include the groups involved through academic research in the development of Green IT. These groups can be financially supported through a mix of international, national, regional or private funding. The innovation in Green IT can come from permanent or non-permanent staff: professors and assistant professors, researchers, postdoc, PhD, graduate and undergraduate students, engineers, etc. These people are linked to the research facility with working contracts.

The researchers are publishing papers and books, participating in conferences as well as in projects and cooperation. Their main aim is knowledge extension and common welfare. The research facility's aim is to be known in the society for good research and education, having projects and cooperation. The researchers can be modelled with their field of expertise and motivation (societal motivation, fully Green IT, partially, or opportunistically?), the amount of publications, the size of the research groups, etc. They are also characterized by strong links among them (compared with other actors) and a better state-of-the-art knowledge.

b – Examples: these actors include pure university research groups or groups coming from research institutes.

c – Leverages for Green IT development: academic researchers can have an excellent research overview due to their permanent exchange with other research facilities. This overview allows them to connect various research ideas and to be up to date with new developments in the research. Due to the participation in conferences, the collaboration in journals and other activities together with researchers from other research facilities a worldwide network of linked researchers exists. This community is interacting on special issues of a well-defined research. This specification leads to a very high level of scientific exchange producing new ideas with the possibility to prove easily if it makes sense to continue in this direction, if this direction can be considered useless or if this idea is already investigated – if yes, what are the existing but not already published results.

d – Boosting or slowing down: with some “freedom” in exploring new and disruptive fields, this actor can be a major contributor in boosting innovation in Green IT. But researchers may miss an industrial link as they are not forced to head for industrial cooperation. This missing link may lead to the fact that the research work and results do not meet the industrial market. However they can also be encouraged by money incentives (directly by companies or indirectly by project calls) to search in one specific direction, limiting their theoretical freedom.

2.3.2. Companies

a – Definition: A company can be defined as an “artificial person”, invisible, intangible, created by or under law, with a discrete legal entity, perpetual succession and a common seal. It is an association of individuals (natural, legal persons or a mixture of both). Company members share a common purpose, organizing their resources and skills to achieve a well-defined goal. For this actor, one major aspect is the turnover of any contract and collaboration. Another characteristic is that the aim of this actor is be the leader of the market in terms of size, money and innovation. A new innovation on the market means a new product and means new clients.

The size of the company and its influence in the target field is also of importance, attracting other companies to their own interests. Their motivation can come from economic or marketing reasons (greenwashing), leading to differences in their behaviours.

Unless this actor is a rather small company the influence on the market, therefore for Green IT can be very important. Within this actor there is in general a strong hierarchy in decision-making and less freedom for the individual to take influence on the direction of the development, the centres of interest and the behaviour of this actor.

b – Examples: In this actors set we find many different companies, from small SME to large groups. Their potential influences are related to their size and importance in the field, until they develop a product adopted widely. Besides the large historic companies like IBM, some new comers investigate especially the Green IT field (to differentiate their business value) and may become the next generation giant (or be brought by them).

c – Leverages for Green IT development: There is always a customer-company relationship existing meaning that the company is close to changes in the society, the first one getting to know new trends, hypes and interests. Companies may react quickly on these changes as a new hype means also a new market for them, hence new business/money to make. A company may also create new hypes in proposing new technologies. In this relationship there is also the impact for developing innovations in Green IT. The society discussing about “being green and greener”, the companies proposing greener products with an additional feature creating a new hype, forcing the competitors to follow this direction and moreover inspiring research institutions and funding agencies to take new directions.

d – Boosting or slowing down: On the one hand companies may boost the innovation for Green IT but on the other hand they also have the possibility to brake Green IT and innovations in general. Companies are in general interested in making money, doing business and to stay on the market. If an innovation would decrease their turnover or favour another brand a company may protect an innovation with the aim not to bring it on the market.

2.3.3. Technology Transfer Offices (TTO)

a – Definition: Technology transfer describes the formal way of transferring rights from scientific research to another party. The aim is to use and commercialize innovative research and results. These rights might be intellectual property in form of patents, copyrights or any other form of IP, depending on the product or result of the research. This process involves invention disclosure, licensing, funded research, also start-up ventures. Milestones payments sponsored research and licensing royalties may appear. Most academic and research institutions have formalized their technology transfer policies meanwhile. Not always these policies fit with the needs of the industry and TTOs have to find the best way to combine the two interests. TTOs are the interface between industry and research institution. Researchers working with TTO can have a higher chance of success to meet the market (and to find collaborations with companies), as the TTO may observe the market, make the link between companies and researchers/research facilities. But they also influence the research directions with financial perspectives rather than societal interests. The individual researcher may be forced by the research facility due to financial reasons to accept collaborations without the aim of common welfare, in a different research interest, or with a forced direction of research as the company may want a confirmation, and not an objective result.

b – Examples: In France, the government created a special company status names as SATT, for Technology Transfer. Some universities created within this framework their own TTO, like for instance the TTT in Toulouse, France (Toulouse Technology Transfer). In other places, the initiative is let directly to the actors in order to create such intermediate offices.

c – Leverages for Green IT development: The technology transfer may be cut into 4 phases: The TTO has a relationship with the research institution. This relationship might be with one specific researcher, with the faculty or with the whole institution. The TTO monitors the ongoing research. The TTO provides links to commercial partners to fund ongoing research. Once the researcher files an invention disclosure with the institution the TTO evaluates the commercial perspectives and possibilities. If there is a potential the TTO will pursue the patent application. Once the patent application is filed the TTO will actively pursue commercial partners for licenses agreements or other forms of alliances. Fee, royalties emerging from the commercialization will be paid. TTO have the aim to become financially self-sufficient but institutions have different aims like societal benefit, the institutions reputation. This actor, having strong links with research facilities, is the youngest agent with a high potential in the system of Green IT [28]. It can shape the researched direction by encouraging links with certain companies. The employees combine the knowledge of (Green IT) research as well as the knowledge about the (Green IT) market. The point is for TTO to be able to understand the still young field of Green IT to find the appropriate partners (may not be as numerous and self-evident than in older science fields).

d – Boosting or Slowing Down: TTOs are boosting new research as they observe the ongoing research as well as the industry and the market they can give quickly a feedback if the research will be accepted on the market and meets the needs of the industry. TTOs are interested in financial independency and it might be the case that they only see the financial return and not the innovation for the society. Generally speaking TTOs are in some countries rather new and it has to be observed if they will become an important actor.

2.3.4. Business Angels

a – Definition: A business angel is an individual providing capital but also knowledge and contact data for a business start-up in a very early stage of their creation. Mainly business angels are successful managers having more experience than the founder of a company.

b – Examples: The World Business Angel Association is an international not for profit organisation with the aim to promote the idea of Business Angels. The aim of this international operating is to stimulate the exchange of knowledge and best practices in angel investing. This not-for-profit organization is based in Brussels and operates worldwide.

c – Leverages for Green IT development: Business Angels have a global view over the industry in their working field. If a start-up needs support at the beginning phase business angels may help. They may provide contacts as well as financial support. Especially in Green IT as a rather young research field business angels are useful as they are experienced managers knowing the markets and potential partners find them more trustable. In the field of Green IT, a still young field, the influence of this actor can be important to help managing the innovation in start-up companies. Members of this actor have a loose link, if there is any. The links are mainly with companies and with a few researchers wanting to create a start-up company or a spin-off of the research group. They provide knowledge in economy and management; they may help in creating business links. However they might have fewer reasons to follow an innovation and boost it as they have more experience on the traditional market, with traditional products. Also, they may not intervene at the same moment in the maturity model than funding agencies and TTO.

d - Boosting or Slowing Down: Business Angels are boosting Green IT as any other business as their support (in giving knowledge, connecting people) is mainly for free, there is no financial interest from their side at the beginning; if the business idea has success this might change. No additional charge will have to be paid by the start-up at the beginning.

This might differ if the Business Angel invests money. Then there is of course a financial interest and the start-up will have to pay back the sum invested. This may happen in exchange of convertible debts or ownership equity.

But like as all other actors Business Angels have to be convinced about the idea in Green IT. They would lose their reputation in case the business ideas with the innovation would not work out.

2.3.5. Governments

a – Definition: At national or international level, governments can certify, regulate or enforce the usage of technologies, based on several factors. These factors can be related to Green IT and sustainability. By voting some directives or laws, this actor has a direct influence on the development in Green IT. Governments rely on experts from research facilities, companies and on Standardization Bodies when laws or directives are created.

b – Examples: The Energy Star program is a widely adopted mean aimed at offering customers the possibility to buy more efficient products than required by law. In US, the Department of Energy is regularly checking the compliance of the products to the Energy Star label, developed by the Environment Protection Agency (http://www.energystar.gov/). The European Union Code of Conduct (EU CoC) is another such inter-state level initiative. Its aim is to inform and foster the improvement of energy efficiency in the planning and operation of data centres. It is also a voluntary initiative to help designing and operating and reporting data centres power consumptions.

c – Leverages for Green IT development: So far, the above initiatives have no enforcement in laws, and their impacts can be seen as insignificant, while it could help speed the processes. However the choice of governments to promote, even without regulations some standards or technologies has a direct impact on their visibility and attractiveness. Fixing an objective for carbon emissions, putting some taxes accordingly or forcing the usage of green products (for instance green data centres) boosts the research and development in the attached fields. This actor reacts on social movements in the society, as well as on recommendations given by international organisations (like UN) and by Standardization Bodies. Even if influential groups are not officially appearing they are having an influence on the decisions of governments and on future laws.

d – Boosting or slowing down: Indirectly, these initiatives have impacts on Green IT development. Customers tend to choose the most efficient products; companies building energy efficient products promote these labels as marketing keys; data centre operating under the EU CoC advertise it, display their increase in energy efficiency, and use it as a commercial advantages. The social direct and indirect influence must therefore be encompassed in the study.

2.3.6. Funding agencies

a – Definition: Funding agencies are organizations providing grants or other forms of support to projects or collaboration. Funding agencies may be non-profit organizations, private foundations, or government offices. The goal of a funding agency is usually to promote excellence or encourage interest in a particular subject. This actor is characterized by the distribution of money promoting collaborations between other actors. Members of this actor act individually; there is no legal agreement signed between them. Sometimes co-funding is possible under certain circumstances: Two research facilities in different countries proposing a common research topic may apply for funding in both countries. This actor can be specialized towards only one kind of actors or may give funding to different actors, mainly companies and research facilities. The funding may vary according to the actor(s) asking for.

b – Examples: The European Framework Program 7 and the new Horizon 2020, or the French National Agency for Research, the German FWF (Fonds zur Förderung der wissenschaftlichen Forschung), fall in this category. Countries may have dedicated agencies for Green aspects, like the US EPA for instance.

c – Leverages for Green IT development: They directly influence the number of collaborations, the size of these collaborations (in terms of hired staff or equipment for instance), but also they can distract the actors from their main goal with administrative burdens for instance, depending on the period of study. They influence directly Green IT development (by money incentives) and also indirectly the society by the results of the funded projects. Innovations in the Green IT are influenced by funding organisations and their open calls as deciding the topics of open calls funding agencies drive research facilities in the direction of a certain research. Before starting an open call experts are invited to give their ideas about new interesting research. And already these experts are deciding the direction of the research for the upcoming years as these calls are in general fixed for minimum one year with a specific deadline to respect. By money incentive, their impact on Green IT development is direct (for the actors benefiting from the grants) and indirect (since these actors will have a societal and economic impact on their own).

d – Boosting or slowing down: These facts create already a difficulty as new research ideas, social movements and upcoming trends cannot be taken into account immediately. Additionally there is the high administrative workload creating difficulties to organisations applying for funding. Looking for partners to have a consortium according to the rules of the funding organisation takes time and not always is the consortium formed by the necessity of the work packages but more because partners are needed to respect the rules of the funding organization. Energy and money is wasted because rules for open calls are too strict, organisations are wasting time due to too much administrative requirements instead of using this time for new research. But their advantage is that they group research ideas and that their research funds are rather large. Funding agencies grant the fundamental research, as other actors implicated in the innovation process are interested in new research and breakthroughs.

The role of funding organizations will have to change to become a real booster for innovative research. It does not mean that the traditional role has to disappear but additional roles have to be created.

2.3.7. Standardization bodies

a – Definition: This section does not aim at giving a full global view on the Green IT standardization initiatives, but rather tries to outline the role and links between and among the standardization bodies [29] [30]. It is based on a study on the standardization bodies in the field of data centre energy efficiency [31], complemented with newer development in standardization efforts.

Standardization bodies can be categorized in three categories: international formal standardization bodies (and their regional, national counterparts); influential groups and professional bodies. This section focuses on the former while the next section will describe the latter.

On Figure 3 : Standardisation stakeholders, one can see that the first providers of materials and tools that may make their way to actual standards are industry alliances, academic researchers, or both in collaborative projects. Some of the proposed ideas may be presented in one or several standardisation bodies to eventually become standards. These standards can in turn be used by governments (national, federal or European levels) as regulations in laws that must (and can) be enforced. Governments can use directly the materials as regulations, recommendations or labels. While the process for formal standardisation take a long time since a consensus have to be achieved between all members (especially states), the direct link with governments is sometimes more efficient. Finally, it must be noted that some metrics, tools, and methods provided by industry and research facilities are used directly by final users and may become de facto standards. In the centre of the Figure 3 : Standardisation stakeholders: Standardisation stakeholders is the certification authority whose role is to certify that the measurements, claimed by suppliers of technologies actually follow the standards, the labels or the recommendations.

Figure 3 : Standardisation stakeholders built from [32]

b – Examples of standardization bodies: The ISO (International Standardization Organization), the IEC (International Electrotechnical Commission), the IEEE-SA (Institute of Electrical and Electronics Engineers Standards Association) and the UN ITU (United Nations International Telecommunication Union) are three important bodies in the Green IT landscape.

c – Leverages for Green IT development: All three standardization bodies have activities in Green IT in general and in data centre energy efficiency in particular. Their action lies in the development of standards, some of them individually, some of them in joint groups. The standards stand from the design, the production, the operation, to the recycling of IT services and materials. Some standards maybe used directly by stakeholders or by States for regulation. This actor, aka ISO, IEC or ITU, influences the environment of the Green IT field with the standards they are promoting, and conversely influence the society at large with their decision. This can be done on a national or international level. They can be influenced by other standardization bodies, as well as by companies and research facilities. Often researchers and representatives of companies participate in meetings, discussions in order to influence the decision taking, the recommendation provided or simply to have an advantage on the business market.

For instance, ISO 14064-1 is used for reporting on greenhouse gases and makes use of the GHG Protocol, while ISO 14101 addresses the environmental impact of an organisation in general. Within IEC, Task Committee 111 is interested in environmental standardisation for electrical and electronic products and systems. UN ITU-T Study Group 5 is evaluating the ICT effects on climate change, publishing guidelines for using ICTs in an eco-friendly way. It is also responsible for studying design methodologies to reduce environmental effects. ITU-T L.1200 specifies the Direct Current interfaces while ITU-T L.1300 describes best practices to reduce negative impact of data centres on climate.

Joint Technical Committees (JTC) are established between ISO and IEC in specific areas. JTC 1/SC 39 is the joint sub-committee on “Sustainability for and by Information Technology”. The framework for describing metrics for energy efficiency is on the move and must be considered when developing new metrics for their standardisation: standards 30134-1 (General Requirements and Definitions) and 30134-2 (PUE: Power Usage Effectiveness).

The Institute of Electrical and Electronics Engineers Standards Association (IEEE-SA) is an organisation within the IEEE developing global standards in a broad range of industries. IEEE-SA promotes its own standards for electronic products. In the Green IT, it addresses desktop personal computers, laptops and personal monitors. The standard covers environmental aspects of a product including the life circle.

At regional level, concerning European standardisation activities on data centres, the Network is done by ETSI (European Telecommunication Standard Institute), the Power infrastructure by CENELEC (European Committee for Electrotechnical Standardisation), the IT management by CEN, the cooling by ASHRAE (not EU specific) and the monitoring by CEN/CENELEC. The need for having joint and coordinated groups is obvious. The establishment of the Coordination Group on Green Data Centres (CEN-CENELEC-ETSI) helps to harmonize initiatives.

d – Boosting or slowing down: Without doubt, the role of standardization is globally, and on the long term, boosting the adoption of a technology and its spreading in the society. However, in the context of Green IT, and IT in general, the duration of the standardization process is often not compatible with the pace of innovation. Reactivity of such bodies is in question to adapt their influence (typically a standard comes after 3 to 8 years…). Depending on the ratio companies/researchers in one standardization body the recommendations are industrial orientated, less or more innovative, common consensus, meaning more or less a pioneer task. Anyway, once a standard is set innovation in Green IT boosts as companies are interested in being labelled according to this standard. One such example is the TCP/IP protocol stack never standardized but de-facto standards. In Green IT, the same applies with the PUE (Power Usage Effectiveness) that is still under development in standardization bodies while already widely adopted (sometimes misused) in industry.

2.3.8. Influential groups

a – Definition: Complementary to standardization bodies, some influential groups propose to enforce and influence development of standards by addressing this issue at various levels. Some are country-based, others are interaction on a global level. Some are purely industrial, academic or a mix of both. Governments can activate some of these groups. Some of these groups can also propose and defend some standards. Members of such a group are mainly individuals; they may represent company's interests as well as their own interests. Within this group there is a loose link, sometimes people pay an annual fee but in return new business contacts are created, an indirect influence on decision-making institutions, local governments can be created.

This actor supports and encourages collaborations between parties inside their groups, by organizing events and helping projects establishment. It may also support collaborations between the group and other actors, especially companies, and moreover start-ups. This actor may provide different knowledge according to the different members. Their size and gathered influence (from participating partners) is a key aspect in their success. This actor operates mainly on local levels. Participants are more reactive than standardization bodies making these actors more subject to innovation gaps.

The aim is having influence on the development of the market, as well as gathering information. Every member of this group may afterwards have different aims, different reasons for joining this actor.

b – Examples: The Green Grid is a non-profit organisation, open industry consortium of IT suppliers, end-users, policy-makers, technology providers and utility companies. The aim is to unite global industry efforts, to create sets of metrics and to develop educational tools. There is a strong link with the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE), The Chartered Institute for IT (BCS) and the China Communications Standards Association (CCSA).

The GreenTouch initiative (ended in June 2015) was devoted to explore energy efficiency in networks. The main goal of this large academic and industrial consortium is to support a reduction of a 1000 factor for 2015. This group explored all levels of technology and innovation associated to networks: wired and optical, wireless, routing and switching, services, etc.

c – Leverages for Green IT development: the influential groups can have a big impact in promoting and developing Green IT. By supporting collaborations and direct links between diversified partners, they enforce the promotion and dissemination of innovation.

d – Boosting or slowing down: like standardization bodies, influential groups have a big potential of boosting Green IT development. But contrary to these bodies, with some disruptive supported approaches (like in GreenTouch), they bypass limitations due to long processes.

2.4. Transferring knowledge

Knowledge transfer is an area of knowledge management concerned with the movement of knowledge across the boundaries created by specialised knowledge domains [33]. It is the transmission of knowledge from one place, person, institution or ownership to another. In [34] different views of knowledge and knowledge management are described with the following conclusion:

“Knowledge transfer is about identifying (accessible) knowledge that already exists, acquiring it and subsequently applying this knowledge to develop new ideas or enhance the existing ideas to make a process/action faster, better or safer than they would have otherwise been. So, basically knowledge transfer is not only about exploiting accessible resources, i.e. knowledge, but also about how to acquire and absorb it well to make things more efficient and effective.” [35]

Technology Transfer in the management literature is usually considered within or across companies, such as the dissemination of information through transfers of employees from one division to another. [36] focused specifically on the flow of technology transfer within a large R&D organization. [37] examined the role of the multinational corporation in facilitating commercial knowledge transfers between countries. It is not easy to separate strictly knowledge transfer from technology transfer.

We consider technology transfer as a part of knowledge transfer. Therefore more specific rules may apply, but general statements stay the same. First is that a knowledge transfer process has two main components, i.e. the source or sender that shares the knowledge, and the receiver who acquires the knowledge. Secondly, knowledge transfer, although looks simple, is complex due to various prerequisites, factors and contextual issues surrounding the process [34].

Compared to [28] we do not examine each single process of how new knowledge, in our case new technology is created and the internal process of a TTO. Nor do we have a look on the management of knowledge/technology as this thesis is done in IT our aim was to give a first model and to implement it in a simulation framework in order to have a base for further research.

2.4.1. Technology transfer with/through mission orientated research

The definition of technology, which is used as the base in this article, covers the knowledge of the appliance of scientific knowledge. Scientific cognizance stands in this case for all results and observations of activities in research and development. The constraint that these results had to be received with scientific methods is not taken into account when the transfer is done: Used technologies might be the result of scientific ambitions but also lucky consequences within practice. Finally scientific knowledge in the perspective of this work encompass both empirical and theoretical knowledge; it means all directed processes and methods, including their practical usage and also material artefacts like products, prototypes and software.

Technology is the special knowledge, know-how, in the sense of instructional knowledge and skills. Occasionally knowledge is divided into know-how, know-why, know-what, and know-who, but simplifying all these definitions are summed up under the definition of know-how. In the economic context knowledge is seen as one factor of production respectively as a resource with an important impact on the technical progress and the long-term development of companies. Technology is the sum of all available procedures of productions in a society. The difference to other production factors is that technology can hardly be measured quantitatively compared to raw materials or capital. The evaluation of the technology potential is therefore very difficult. However, technology is never consumed during the usage or dissemination, the user, the researcher or the teacher is not losing the technology. But technology can lose importance in case the exclusive usage is lost and/or new knowledge is creating new technology, hence the value of technology can be reduced.

Changing the perspective from the generation of technology towards its usage leads to another useful restriction. From this angle of view technologies represent all results of research and development contributing to solutions of problems. The reference to the usage of technology suggests linking the term technology to the interaction between scientific –technical perception and the society.

This dissertation doesn't lodge claim of a complete classification of interactions of parties in all sorts of technology transfers. This is not feasible as classifications can be done with different parameters (vertical, horizontal, product-oriented, procedure-oriented, infrastructure-oriented transfer, etc.) [38] [39] [40]. To examine each criterion in an isolated way has only a limited value for the global point of view. Therefore 2 kinds of transfers will be presented in the following to reach a profound comprehension of the investigated subject: Nonpointed and focused transfer.

2.4.2. Nonpointed and focused transfer

Within the area of nonpointed transfer the technology-disposer provides information to for him unknown public. The receivers decide about the individual relevance of the information and about the implementation of the information. There is no direct contact between the provider and the receiver. Nonpointed technology transfer is often defined as a process in which ideas are spread from a provider to the receivers [41] [42]. These definitions are pointing out the passive diffusion from the origin to receivers using this knowledge. The technology provider offers – knowingly or unknowingly – a potential solution, in general without having an idea of the concrete request. An individual adjustment is not possible due to the missing interaction.

The basis of the diffusion is the availability of the technology by the producer. This can occur in a communicative way like presentations and publications or due the carry forward of the technical artefact.

With the focused transfer it is possible that a precise solution is transferred target-oriented to the recipient. In this situation the partners are in an equal position. Mainly the constructor modifies and develops the technology according to the needs of the user. The developer has an active role as he supports the user in the implementation and in the gainful use. Therefore you need an interactive relation between the partners. This active interaction results in a lot of work but also it boosts the success of this technology. This technology transfer is similar to a vendor-client-relation.

The difference between these 2 models is shown amongst others in the different observation level. The nonpointed transfer can be seen as a process of diffusion of an ideal innovation in a social system. The interest in the focused transfer is in the microeconomics, highlighting the relation between 2 or more economic entities. The questions of interest in the nonpointed transfer of technologies are the rate of spread, kind of spread, channel of diffusion, and classification of technology users. In the central research of the focused transfer are the characteristics of the transfer partners, the interaction process, and the implementation process. The nonpointed action is uncontrolled, unmanaged and spontaneous; the focussed transfer is controlled and precise. Crucial is if the technology constructor who is sending implicit or explicit information defines a selected user respectively a defined and limited circle of potential users, who he has already a relation with.

Having a nonpointed technology transfer and the offered solution correspond to the challenge of the potential user, then a similar benefit may be achieved as with a focused transfer. The nonpointed transfer can’t replace the focused one but may result into a passage from the nonpointed to the focused transfer – assuming the willingness of both partners.

2.4.3. Contracted research between research facilities and companies

For innovation oriented companies represents the academic research a fundamental resource of external produced technologies. The more the industry is oriented towards novelties on the market and leadership in technology, the more the cooperation with public research institutes is interesting for it. Research facilities could be considered as the best partners as they have a wide experience in cutting-edge-research but also because their interest is not only focused on one product. They have no business interests, but an interest in independent and fair research – they are impartial! Despite this high synergetic potential researcher and industry operate in unconnected systems. In reality there exist a variety of options for arrangements in the cooperation, like patents, licences, specific consulting. Contracted research is a specific form of focused technology transfer with its challenges and chances for research projects and for future cooperation between industry and research institutes. In the contracted research there is the presumption that the company contracts a research to a university for implementing the result out of this contract in its organisation, using this outcome and having an advantage in competition. The contracted research project is the instrument for the technology transfer.

Contracted research is getting more importance during the last years and it is finding also the influence in national and international research programs, calls of tender and open calls [43] [44]. The idea is to define certain criteria for this special way of transfer.

General definitions of contracted research:

- There is a client-supplier-relation
- The client is the company
- The supplier is the research institute
- The primary purpose of the cooperation is the exchange of scientific knowledge
- The transfer is interactive, organisational, service based, focussed, and between 2 organisations
- The relation is based on a contract
- The contact is based on a contract
- The contact is temporary and has the character of a project.

2.4.4. Comparing research facility and company points of view

With a contracted research project a temporary bridge is built between the system of economy and the system of science. To be successful elements of both contexts have to be taken into account and further stimulations have to be provided [45]. The interaction between partners with different background and a different environment is challenging. The internal systems can't be compared and assumptions may often be wrong because of a lack of knowledge about the other partner. In [28] a very short overview about different aspects of companies and research institutions is given. I propose the following table presenting a larger overview about the different aspects of the two partners of a contracted research:

		Scientific research	Operating Research and Development
A	Organisation	Research institutes (Universities)	Companies
B	Duties/responsibilities	Common welfare Extension of knowledge	Profit orientation Offering service and products for the market
C	Core competence	Basic research Experimental research User oriented research	User oriented research Product development
D	Criteria of efficiency	Scientific reputation	Profit and company value
E	Approach	Search and find General	Decide and act Concrete
F	Criteria of quality of the work	Systematic production Reconstructable processes and results Big application area Explanatory contribution	Usability of the results Big effects for the clients usage

			Advantageous economic solution for a concrete application areal Production of an innovation leading to a temporary monopoly position
G	Reference groups	Scientific community student	Clients Other units within the company
H	Distribution of the results	Conferences Publications	Products Internal processes Services
I	Priorities of topics	Personal interests Expected appreciation Financing	Strategic development of the company Portfolio of the products
J	Selection of topics	Autonomic Funding relevant	Innovation management Top management
K	Freedom of action	Very high Limited through resources	Low compared to research institutes (universities) Limited through the management
L	Organisational framework	Fixed and solid Influenced through scientific community Need safety concerning the expenses	Flexible Influenced through market needs, clients' needs Searching for information about efficiency and risk
M	Relation with other units of the organisation	Limited administrative support is offered Interaction within a given framework Parallel units with other fields of competences	Part of a chain within the company Management gives the targets
N	Funding	Non-performance related basic financing Calls of funding organisations Services for companies	Budget of the innovation management In-house accounting
O	Staff	Long-term staff and short-term staff	Long-term staff

Table 7: Elements of comparison of point of view

For the line B there is currently a big hype in our society about all topics related to Green IT. Therefore companies are interested in having a green label on their products or that in their name "Green" is appearing. It is their way of showing that they care about our planet. There are many different aspects making IT to Green IT. It starts with the production over the usage, the energy consumption, the cooling towards the recycling. The individual funding enterprises can get from the state, from individual programs are quite high, therefore they are interested in getting the "green label" even if it is only "green washing". The Industry is more aware of this hype because they see the new market for business and for extending their field of activity than researchers who are more interested in long-term research, in a contribution to the welfare of the society. These 2 different approaches will also lead to developments into different directions.

Consider line D in the Table 1. The problem for the scientific community is that there are not a lot of conferences dedicated to Green ICT and having a high reputation in this young research field.

For instance, IEEE IGCC [46] started only in 2009, ACM/IEEE e-Energy [47] in 2010, IEEE GreenCom [48] in 2010, while workshops attached to larger events started a bit earlier (HPPAC [49] in 2005 or E2GC2 [50] in 2009), and so on. Academic journals on sustainable computing or Green It have been launched only recently by major publishers ([51] in 2011 for instance). Academic initiatives attracting interests such as Green500 [52] or the European COST Action IC0804 [25] are also not very old.

For researchers there is a difficulty to publish paper in well recognized conference or journals, and to reach at the same time a large community interested in energy saving, therefore to get forward in their carrier is more limited than in other well-established fields of research when they dedicate solely their efforts in this green IT field. Researchers may prefer to publish in other related medium to increase their visibility and reputation (for instance conferences existing since 20 years having some tracks on Green IT rather in specialized events organized since only a couple of years).

For companies, the label "Green" adds more value to their products as in our society the awareness of protecting the environment is already quite developed; even on the market "green products" are bought for a higher price. Moreover, a company which is well known for their "green products" is having a higher value-monetary, but it is also having a higher reputation.

This criteria in the field of efficiency shows totally divergent points of view, and may result in difficulties in the transfer of technology and building up a long lasting cooperation

In the line E concerning the approach the operating research and development departments in companies prefer simple solutions. Solutions, which are not costly, working immediately and non-high-maintenance products are definitely the ideal outcome, the perfect serviceable knowledge. Even if with more investments e.g. measuring the load of servers, or thinking about different methods of cooling the companies could achieve better solutions they keep in mind the profit and the management is setting the priorities – see line J.

While for research institutes it is more important to have a general approach, to look after complete solutions, applicable in many cases. Costs are less important, and also the time, which is needed to achieve results, is not the main interest of the research institute. The research institutes are opened concerning new approaches, new ideas. The researchers are free in their decision which research to bring forward and where to put the focus. This effect may lead to difficulties between researchers and the management as the company sold a certain result to one of the clients and is not able to change the contract, even if the solution proposed by researchers have better results in saving energy.

Considering lines E and N together there is also a mismatch between companies and academics as partners and the different funding organisations. Funding organisations are pointing out that accepted Green IT projects have to be innovative, ambitious with a new result at the end of it. It is also now almost mandatory that in each project (national or international) industrial partners have to be included, mainly as end-users of the results. Researchers are investing time and energy to find new innovative ideas concerning the topic Green IT and they try to convince companies about their value of Green IT (e.g. new cooling systems, changing the server load, …) for the industry. But being innovative is not the only aim of companies, therefore they hesitate to invest time, money and human resources in building up projects, in which they do not see an immediate outcome. Researchers need to contact a lot of potential industrial partners to convince them about Green IT, and about its usefulness in their company. In this process also the hierarchy is causing problems as the decision makers in the companies are not having the inside view like someone working directly in the IT department and having the knowledge of technical details and the potential of innovations. The decision makers inside the companies want to see concrete numbers about energy savings, or less expenses for hardware, while with innovative research it is not easy to produce these numbers before implementing the technology. The status is: Researchers have innovative ideas, potential industrial partners hesitate, and the funding organisations are requiring innovative projects with industrial partners.

The different funding possibilities are an additional topic for the line N. At research institutes you have sometimes Technology Transfer Offices or Project Service Offices providing support concerning the different calls of funding institutions and the financial support offered by each call. The difficulties are that each call is having different rules, different frameworks, and conditions. Researchers who are working regularly with these institutions are familiar with the expressions, the registration of projects and the numbers you need for the general budget. For companies participating in projects it is more complicated as they have to investigate the program, the framework and their possibilities of getting funding, especially for SMEs. In participating in European Community projects they may get funding for staff and equipment directly from the program but they may also get some tax advantages. Especially for companies gaining their first experiences in research projects these gathering of information may lead to an increase of costs for the preparation of a project, which outcome is uncertain. It is even uncertain, if the project is accepted by funding institutions; meaning all the investments would be lost for the company.

Concerning the funding of projects the companies and the researchers also have to take into account that between having an innovative idea, the starting the construction of a consortium and the acceptance of a project there may pass some time. Meaning, for researchers but also for companies it is necessary to have a certain planning about the human resources, the workload and the involvement in other projects. All these components have to be taken into account but there is always an uncertainty concerning the future topics of open calls (Will there be a green aspect?), of the acceptance of projects and the constraints of project partners. Especially for SMEs this could create problems. In times of crises – like nowadays - a strategic planning for companies in participating in project is very important, unfortunately there are not many institutions providing efficient support to industrial partners. While at universities the situation is getting better during the last years as universities are more receiving their independency and therefore they have to get more accepted projects to fund their research and additional staff.

Considering line I an interesting aspect may appear. Let’s take the example of focused transfer orientated on server virtualisation technologies or Cloud Computing, meaning decreasing the numbers of needed servers to handle user requests to services. As the researchers have the autonomy to choose and/or to change their research field they can focus on a side effect: A nonpointed transfer is occurring as less servers mean less maintenance costs in terms of human resources and hardware changes. But it also means less energy consumption-meaning Green IT is only a side effect of server virtualisation and is appearing as a nonpointed transfer of knowledge as of course the researchers will report this effect. This new knowledge, this new approach may lead to a new upcoming cooperation, to new focused transfer.

Unfortunately not in all research field of Green IT such loops can exist, but of course it is necessary for our society that side effects of research are taken into account for future projects and co-operations. There are various examples like the development of cooling systems for data centre, which was leading to new metrics like the PUE (Power Use Efficiency). The way to optimize the PUE is to use alternative cooling such as free cooling with ambient air, hot/cold aisles, water cooling,…. While these techniques should actually reduce electricity costs, this is unclear, since this may increase the amount of IT infrastructure actually deployed. The importance is to see that all kind of transfer is having influence on other specialities in the field of Green IT and developing the technology.

2.4.5. Proposition for the transfer of Green IT

Based on the previous sections, I can propose now the following leverages to accelerate the development and the technology transfer for Green IT solutions:

- Currently in the context of Green IT the success rates are too low to guarantee the participation of excellent researchers and industrial partners in the long term. A large number of proposals with good evaluation scores remain without funding due to budget limits. An increase of budget dedicated to Green IT and Green IT conferences is necessary.
- For project applicants a transparent funding decision throughout the whole evaluation stages, even in the ranking of proposals would be useful. Especially to show that the Green IT can participate in various projects also in other disciplines which are not only dedicated to IT.
- The time between project deadline and acceptance should be reduced to a minimum, as especially in Green IT - as a young research field - there are a lot of SMEs participating. These SMEs have to plan more precisely their activities, their investment of human resources and to guarantee their active role in a project or in several projects it is evident not to lose too much time for the evaluation.
- Smaller, targeted projects and larger, strategic ones are needed, but there should be the possibility to fund small targeted projected without the need to invest months in searching for big partners. Many small innovative companies are looking for market niches, which can be still found in Green IT as focused research may lead to nonpointed transfer of technology. These projects may only have 2 partners but they may have an innovative outcome with influence on broader research.
- Possibilities for small projects to evolve into larger cooperation should be foreseen. Small projects often start with a spin-off and a research institute, but at one point it might be necessary to open to project to other partners. Green IT is having the capability to enter in many already existing projects and partners shouldn’t hesitate to contact already funded project to do some measurements or to exploit an already existing structure.
- Obstacles are the different funding schemes for the different calls. Simplifications are needed! But there is also the possibility to sign contracts between research institutes and companies to fund research and to transfer technology. This is not only possibly on the national level but also between different countries. This would insure that the transfer

of technology is getting different cultural input, and maybe new aspects are discovered- because of different laws, because of different environment. Simply take the effect of free cooling in the IT. Researchers and Data centres in the North of Europe observing the possibility of free cooling being a part of Green IT are facing different conditions than the same project would face in Southern Europe where it is not possible to construct a data centre and to think that the temperature of the environment would cool the system during the mainly during the year.

- Foundations of project service offices should be supported by the funding institutions. Before a project consortium is built these offices should get in contact with independent experts in the field of Green IT to explore the possibilities of cooperation on the international and national level and to judge already the innovation. As these project service offices and the experts are linked with different organisations the procedure of building a new consortium is less time and money consuming, and may also result in nonpointed transfer of technology in Green IT.
- The focus on excellence and strong institutions in EU research support leads to economies of scale effect: the few big institutions and companies become ever stronger while the rest of the research community and SMEs are not included. Therefore umbrella organizations should be created to support the exchange of knowledge, the cooperation and outsourcing from larger to smaller companies can be discussed.

Chapter 3. Defining the links between actors

In this chapter, we focus our interests towards the links between actors. First, following the interests of knowledge transfer and the different levels of collaborative research exposed in Chapter 2, a discussion is given on the different possible links between the actors. Then a selected set of links are defined and more particularly studied, to understand their potential and limits for boosting technology transfer.

3.1. Introduction

Not only the different actors and their attributes are important to be defined but also their links to other actors within the system. There might be links accelerating the development of new technology as well as slowing down partly the cooperation.

A link is defined as a state of being connected – between two institutions as well as between two persons, or an institution and a person. This might be by contract, or a Memorandum of Understanding (MoU), or a personal relationship like being co-workers, members of the same institution, company, or working, being in the same environment (even in different countries).

A contract represents the strongest possible link between actors, while a personal relationship is the loosest one; not meaning the moral obligations are less, but the legal obligations are less important than being linked by a contract.

As stated before, the different actors interact. Interaction is defined as the process by which different things affect each other or change each other. These interactions can be of several kinds: between actors of the same group (e.g. between researchers) or between actors from different groups (e.g. researchers and companies). Formally, one should detail and study all the links between all the actors in the section 3 and 4. I determined 8 actors, meaning a potential for 36 links to be explicitly detailed. I argue here that, among all these links, some have higher impact on the development of Green IT than others, or have the potential to have more impact if such links would be established.

The following table gives an example of the potential links between actors and categorises the strength of their links. Among these, selected links will be further detailed in the following. The choice of the selected links is based on their strength and their impact on the model developed in Chapter 4.

Link			Influence on Green IT
Research Facility	<->	Research Facility	Strong
Company	<->	Company	Strong
Research Facility	<->	Company	Strong
Funding agency	<->	Research Facility	Strong
Funding agency	<->	Company	Medium
Standardization	<->	Company	Medium
Standardization	<->	Influential groups	Medium
Standardization	<->	Regulation	Medium
Influential groups	<->	Company	Strong
TTO	<->	Research Facility	Strong
TTO	<->	Company	Low
Business angels	<->	Research Facility	Low

Table 8: Example of links between actors

Following the formalism used in the previous sections, I detail in this section some of the links by defining them (which actors are involved, what is the nature or the object of the link, which metric could be used to assess this link strength), giving some examples, what is the influence of this link on innovation in Green IT, and what is the impact of this link for boosting or slowing down the process.

The first obvious link is when some formal contracts between parties are established: A funding agency is granting several research groups and companies to elaborate in a research direction, more or less mature for market. Obligations of the parties are given in the contract, deviations are reported; risk is mainly on the shoulders of the funding agency. In this schema, the amount of money granted and the rules for attribution of this money (often 100% funded for research facilities, partly funded for companies) are keys to evaluate the potential impact of the interaction.

A direct link between one research group and one company through contracted research is another possibility. In this case, the stakeholders being clearly identified and the subject more narrow, the key for success is the trust one have to the other (trust in capability to raise funding, trust in scientific value - reputation, trust in company involvement).

3.2. Links between Research Facilities

a - Definition: This link is created between institutions but in concrete this link is the most common practice for researchers. Research work is done in networks, and this link represents the actual joint research output. Researchers have in general a loose link created by having the same research interests, attending the same conferences, seminars, publishing a common paper or organizing a workshop or conference. It can be assessed by the number of joint publications in Green IT, the number of regular visits, and also, PhD co-supervisions witness a link. These engagements are personal or maybe involve the research group to which the researcher might be attached.

Researchers have a – limited or unlimited - working contract with the research facility they work for. Additionally to this contract there is also the labour law stating duties, responsibilities, and rights. Researchers are employees of the research facilities with freedom of action in their research. They can never represent the research facilities for any legal action. They represent their own (or the research group's) research ideas. An existing problem for research, not only for Green IT is that research staff is changing a lot. In general a contract may last up to 3 years – the runtime of a project - but in reality the turnover of employees is much higher. This creates a permanent flow of knowledge, and sometimes a lack of knowledge when a researcher leaves a research facility. Especially when this employee starts a carrier in a company the link to research facilities is often lost and with it the knowledge for the research facility.

To facilitate the interactions of researchers working in different institutions a Memorandum of Understanding (MoU) might be signed by the institutions. This expresses the will between the research facilities of cooperating, indicating a common line of actions in the future. It is often used in cases research facilities do not have a signed legal contract for a project but the researchers want to have an exchange. Often the MoU is the first step of a project proposal avoiding obligations under international law.

If researchers get engaged in a wider project or cooperation it is the research facility as an institution overtaking the legal and financial responsibility. The researcher has the freedom of research within the framework of the project during the runtime while the research facility is the official partner in the project.

b - Example: The PhD candidate writing a chapter for a joint publication is co-supervised and produces papers, scientific report and research protocols with both research groups. This is probably the most effective way of knowledge transfer between two research facilities. Regular meetings are taking place and there is one person as an intermediary between two institutions. This person gathers the knowledge of the research facilities and transfers the knowledge.

Also the COST (European Cooperation in Science and Technology) Action IC0804 (www.cost804.org), and the new-born IC1305 are examples of such networks in the field of energy efficiency in large scale distributed systems (such as Cloud, HPC, Networks, …) and ultrascale computing (up to exascale). It is not the research facility but the researcher nominated by the National Point of Contact in charge. The links created during such an Action may lead to new projects and cooperation.

As an example for a project of various research facilities and industries the CoolEmAll project might be mentioned. It was an EC-project with a runtime of about 3 years. An EC-project is one of the examples where the research facility gets involved as an institution, signing the legal contracts, negotiating the Intellectual Property Rights (IPR), making working contracts, writing financial reports while the researcher(s) involved are in charge of the quality within the project.

c - Action means of this link for developing innovation in Green IT: Each research group, each researcher in research facilities has a certain level of freedom to investigate a particular topic, hence Green IT can be one of those. Each researcher is free to collaborate with other researchers in his research field. It strongly depends on the individual researcher how many interactions are set up.

Some funding agencies may choose to favour Green IT if they already see some strong collaborations and high-level publication results between partners. For instance, the COST office decides which Actions to fund: The presence of the named funded networks clearly put forward the research in Green IT. Not to be forgotten is the intrinsic scientific reputation of each partner (leading to more or less strong commitment to collaborate).

d - Boosting or slowing down factors in Green IT: While research group have the capability to collaborate easily, it certainly boost Green IT research when their choices is in this direction. However, two factors may limit the impact of this link:

First is obviously the lack of money to hire staff or students to pursue or support the research, meaning the allocated grants are not in line with the ambition. Hiring staff is only possibly when projects or cooperation with money flow towards the research facilities are started. The first difficulty in starting a project is already if there is an open call fitting to the interests of the researcher, the research group. Not every time in an open call Green IT or research related to Green IT is a topic in funding organisations. Additionally, new, preliminary data show the average odds of getting a grant from the EU's €77 billion Horizon 2020 research and innovation programme has fallen to between 12 and 14 per cent. Researchers have to take these two steps before new staff might be hired.

Second is that a link may lose importance in one of the research group independently of the partner, due to a new policy of the research facility or better opportunities or growing links in other fields: One cannot do everything and interests may change thanks/due to the above mentioned freedom. The society has to care for the interest in this topic. Energy saving, and therefore Green IT should always be a topic of discussion. Like this common welfare is provided by new research ideas, new "greener" results will be on the market. Additionally, Green IT should become a subject in academic education, as it is already the case e.g. in the University of Leoben, Austria, where you can study Coalmining with the focus on Industrial Environmental Protections.

3.3. Links between Research Facilities and Industries

a - Definition: This link is probably the oldest one existing beside the interaction between research facilities. It is also one of the most controversial and crucial one in transferring technology. This link is essential for the full social return of R&D investments. [53], [54] Literature and numbers show an increasing level of academic commercial activities [54] [55], [56] [57], increasing research joint ventures [58], and joint scientific publications [59]. In [60] there are five broad categories of interaction between researchers, hence research facilities and companies: creation of new physical facilities, consultancy and contract research, joint research, training, and meetings and conferences. There are two neglected issues in the understanding between research facilities and companies presented:

- Joint research projects, consultancy and training have been neglected while policy initiatives were focused on engaging researchers in patenting, licensing and creating new companies.
- The role of individual characteristics versus institutional characteristics is not well investigated so far (i.e. the institutional affiliation of university researchers)

The role of Research Facilities was changing during the last decade. They were and are becoming almost an industrial partner in collaboration even if differences are still existing as you see in [27]. The link represents the contractual interaction between research facility and company and the value added to both partners with this (close) cooperation.

In the bidirectional technology transfer the transfer from companies towards research facilities is neglected. This link exposes researchers and research facilities to a large range of problems opening new research ideas. Companies are confronted with real-life scenarios, researchers may not have direct access to.

b - Example: There are a lot of examples existing but as these contracts are confidential it is impossible to name all examples. Possible partners of research facilities in the field of (Green) IT are IBM, Microsoft, but also energy provider as well as big energy consumers.

c - Leverages of this link towards Green IT: This link is important for each development in the field of Green IT. Companies are interested in new technologies for being the first one on the market and gaining money. Cooperation with research facilities is maybe cheaper than having an own research department. For research facilities it is an advantage having links with industries: Industry may finance research in paying for students, or paying for results. In overall it may be a win-win situation.

d - Boosting or slowing down: This link depends probably the most on the contract(s) signed by partners. As [61], [62], [63] show researchers, hence research facilities interact with companies for a various set of reasons: Increase of research, access to industrial facilities, applicability of research are some of these. It is unlikely that with only patenting, licensing researchers may get motivation for an industrial collaboration. There has to be a variety of interaction channels making it simply to exchange.

As the partners have different interests as you see in section 2.5.4. These differences are slowing down the impact on Green IT as it takes a long time to define common interests and goals. This may change in the future as TTOs were created and their impact will be seen in several years. A company may also hide new technologies if these represent a danger for the business. In this case it is not slowing down but stopping the innovation. In a lot of cases the interaction between industry and Research Facility is boosting the innovation in Green IT.

Technology transfer may also happen due to staff moving from a research facility to a company at the end of a project or cooperation. This is a very efficient way of technology transfer as there is only one person as a sender and receiver of the new technology. The process of technology transfer requires additionally to the technology also the knowledge about how to transfer it. [64] Additionally it has to be known how this technology will be used in the new environment. If only one person in the sender and receiver is in charge of the technology and the tasks there is no loss during the communication between company and research facility.

Knowledge transfer has several advantages [65] and we consider that these advantages are also in the field of technology transfer.

- Reduced errors (e.g., by not repeating mistakes)
- Improved quality (e.g., by using best of breed practices)
- Speeding up decision making (e.g., by getting better cross-functional coordination)
- Lower costs (by quickly identifying expertise) or provide value for money
- Speeding up training (e.g., by attending to common mistakes and learning from best practices)
- Learning and innovation

3.4. Links of TTO with Research Facilities and Companies

a - Definition: This link is one of the most crucial if research facilities, hence researcher, research groups, faculties want to commercialize innovations, results, and research. TTO (should) watch the ongoing research carefully in order to see important outcomes immediately. Important outcomes have to be seen under the scope of industrial importance. This link represents the value of a research facility for the industry.

b - Example: A lot of research facilities have a TTO now, but maybe they do not have this name as e.g. the project service office (PSB) at the University of Innsbruck. In France the government created the SATT having the function of the TTOs. As research facilities are mainly independent now, each may have a different contract with the TTO in charge.

c - Leverages of this link towards Green IT: As TTOs are the interface between research facilities and industry the influence on Green IT and a new research direction is rather high. TTOs are aware of new hypes in the industry and may therefore influence due to the relationship with the academic research. TTOs may give advices concerning the direction of the research, meaning it is the duty of the TTOs to discover new hypes on the markets and to encourage research facilities to enforce the research for the industry.

d - Boosting or slowing down: TTOs and their interaction with research facilities may boost as well as slow down the innovation. The daily business of TTOs is dealing with contracts, IP, and research therefore TTOs and their relationship with research facilities is clearly boosting the innovations as administration takes less time, people working for the TTOs are up to date with research, in best cases they were researchers before working for TTOs. A close relationship between TTOs and research facilities is clearly an advantage for collaboration within the industry. On the other hand there is a 3rd party joining and what was so far a contract between 2 parties (Company, Research Facility) is now turning into a virtual contract between TTO, company and research facility. Even if TTOs represent the research facility they also have the interest to become financially self-funded. Their interest is to gain money in selling results and this may slow down the smooth flow between Company and Research facility.

3.5. Links of standardization bodies and influential groups

a - Definition: This link details the relationship existing between standardization bodies and influential groups. The metric for assessing this link can be the ratio of representative from each influential group in one standardization body, in terms of absolute number and percentage. This will help to figure out their respective weight in the decision process and final adoption.

b - Example: One such example are the ISO/IEC Joint Technical Committees. Despite between open to members of the participating countries, there are only a few number of academic researchers in the formed groups, for reasons outlined earlier: Motivations in that case for researchers are linked with their scientific reputation and career, and involvement in such bodies is not a key for these. More specifically, the JTC1/39 group mentioned earlier is strongly linked with the Green Grid in particular for defining the Power Usage Effectiveness (PUE) first described by the Green Grid in 2007 and definition refreshed in 2012 [66], and now considered for standardization. When looking at the editors and contributors of the reference document from Green Grid, there is only one academic out of 29, and 20 companies represented. Only large IT-related groups are present in the list.

c - Leverages of this link towards Green IT: As explained earlier in 3.1 and 4.4, the impact of standardization and governments can be high. The stronger the link between influential groups and standardization bodies, the fastest the development could be. Indeed, standardization activities suffer from a long process duration that cannot be followed by individuals, and only structured groups can actually influence choices.

d - Boosting or slowing down: Mostly driven by company-paid officers, standardization initiatives are therefore encompassing the interest of companies, member states trying to effectively defend their industry. One example comes with the metrics for assessing the efficiency of the data centres. Each country may participate in the final document for standardization (and eventually vote for it). However, it should be noticed that the groups following this work are small in each country, and basically represent the same interests (sometimes even they are the same people). Other examples also discussed in the JTC1/39 group are the WUE (Water Usage Effectiveness), CUE (Carbon Usage Effectiveness) and the more controversial GEC (Green Energy Coefficient). This latter promotes the use of green energy (which has also to be defined). Every country, protecting its industry, may behave differently in front of these metrics. For instance, France electrical power source is nuclear. Data centres located in France benefit from a very good CUE value, but may have a bad GEC value compared to Canada for instance where power comes from mainly from water plants. The choice of which standard may emerge for regulations (for instance in EU directives and laws) is therefore a strategic issue for governments and industries.

3.6. Links of Funding Agencies

a - Definition: This link details the relationship existing between funding agencies. This link is very loose, as several funding agencies may exist side by side without any interaction. Cross-national programs may exist; nevertheless the research project has to be accepted by both agencies without any consultation of the other funding agency. Therefore we say that there is only an informal link existing.

b - Example: ERA-Net - CHIST-ERA II (European Coordinated Research on Long Term Challenges in Information and Communication Sciences & Technologies): In this program there are maximum two calls per year for transnational projects. It is cooperation between national (and regional) research funding organisations mainly in Europe and is supported by the European Union. It is not only strengthening international projects but also multidisciplinary research in the area of ICST with the potential to lead to significant breakthroughs.

EUREKA - A Network for Innovative and Market-Oriented Research offers cooperation opportunities and support to companies and research facilities. The governments of all member states and the European Commission provide support in a decentralized network. The financing of EUREKA projects varies from Member State to Member State. Project participation can be financed using own funding, public grants, loans or venture capital.

c - Leverages of this link towards Green IT: The leverages could be high if there would only be more open calls for Green IT. This fact is like for any other research field. Green IT is in most calls considered as a part of the proposal but rarely do we find calls including 100% of Green IT.

d - Boosting or slowing down: Funding agencies have the potential to boost as well as to slow down. The most crucial is to have enough funding and open calls for Green IT research as well as projects.

3.7. Links of Funding Organisations with Research Facilities and Companies

a - Definition: This link is very individual and depends on the role of the research facility and the company in a project or cooperation. Of course there is a binding contract between the consortium members (consortium agreement, short: CA), as well as a contract between the funding organisation and the project leader. This contract often called agreement regulates the rights and obligations among the Participants of an EU Project with reference to management structures and financial distribution but also concerning confidentiality, liability and Intellectual Property Rights (IPR). Contrary to the Grant Agreement (GA), the European Commission is not party to the Consortium Agreement. The CA is a contract between the Project Participants and is signed by each one of them. The Grant Agreement (GA) including its Annexes precedes the Consortium Agreement.

b - Example: As an example you may take any project or cooperation funded by a funding organisation. There is the CoolEmAll project (tricoryne.man.poznan.pl.) and under http://www.desca-2020.eu there is a CA proposed for the H2020.

c - Leverages of this link towards Green IT: This link can have a big influence as research facilities and companies may influence funding organisations in order to have more open calls in Green IT, to convince them that Green IT has an impact on the future and can provide excellent research results. Therefore not only the link is influence Green IT but also the institutions and the individuals. They guarantee the success of projects and cooperation, and this encourages funding organisations to put more money inside.

d - Boosting or slowing down: This link can clearly boost innovation if projects and cooperation of companies and research facilities have a good outcome. Only results can convince funding facilities to invest and to make efforts into the direction of Green IT.

3.8. Conclusion

We found out that the different actors are more or less important on the development of Green IT. They may boost or slow down the innovation in this important field of research for our society. Overall we say that researchers, therefore research facilities, as well as companies and TTOs have the most important influence of all these different investigated actors on the innovation in Green IT. Beside the fact that the whole society is concerned, these three actors and their various ways of interactions and collaboration have a huge impact on Green IT. Research institutes, companies and TTOs gather the latest discoveries as well as the capacities to influence and to boost research, hence innovation.

But not only the actors also their interactions may boost innovation, hence Green IT. In this work we were not able to investigate all possible interactions and not all possible existing structures of actors. Currently it is not mandatory for universities to have a TTO, companies may have their own research departments, which may result in an easier exchange of knowledge. Business angels have different ways to interfere and to act.

All these interactions and these different structures of actors should be examined more precisely and especially in terms of boosting Green IT. This will have to be the topic of further scientific research. In creating specific models for cooperation between 2 or several actors taking into the account the specific characteristics of participating actors we see the possibility to even predict the success of projects and cooperation. Success means in this case: Boosting the cooperation for Green IT!

Chapter 4. Using MAS to model the complexity of actors and their links

In this chapter, I use the definitions of the actors and their links proposed in Chapter 2 and 3 to model the complex interplay between them, so as to be able to understand their mutual influences. I decided to use multi-agent systems (MAS) for this modelling due to their ability to model complex environment composed of different types of interacting entities, each one having its own personal objective.

4.1. Multi-Agent Systems

Originally multi-agent-systems (MAS) came from the field of artificial intelligence (AI). Firstly, this field was named distributed artificial intelligence (DAI). The objective became to reproduce knowledge and reasoning of several heterogeneous agents that need to coordinate to jointly sole planning problems [67]. While [67] focused more on the agents and giving a definition, [68][4.16] investigated the organization of multiple agent interactions. Multi-agent-systems provide a procedure to state questions in social and natural science. Researchers in this field used ideas from social sciences: sociology to define interactions of agents, linguistics to give agents a language. Ecology has today a keyrole as interactions of agents with their environment is an issue, and exactly this plays also a role in economy. Therefore a wide range of interactions with research in economy exists.

Multi-agent systems are nowadays an umbrella term [69] for
- interacting hardware agents,
- systems of interactive software agents and
- simulations of multi-agents.
-

Figure 4 represents a multi-agent system: each agent has a goal, and a view (a representation) of the world with which it interacts through communications (with other agents), actions and perceptions with the environment. A multi-agent system is therefore built of:

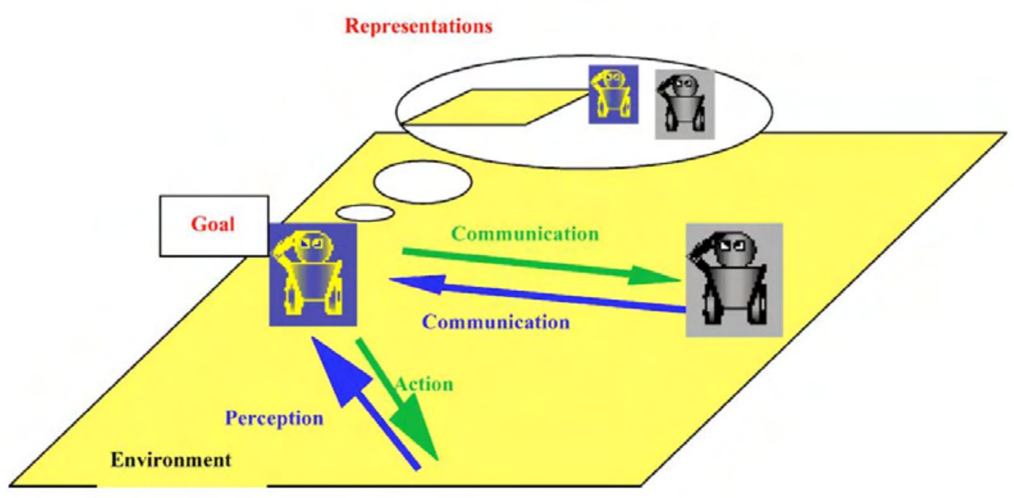


Figure 4: A multi-agent system built from Ferber, J., 1999 [70]

- An environment E, that is usually a space.
- Objects O, situated, that is to say, it is possible at a given moment to associate any object with a position in E
- Agents, A being specific objects and represent the active entities in the system
- Relations R linking objects
- Operations Op making it possibile for agents of A to perceive, produce, transform, and manipulate objects in O
- Operators with the task of representing the application of these operations and the reaction of the world to this attempt at modificatin, which we shall call the laws of the universe

The key issue in any Multi-agent systems is to formalize the coordination among agents. There are 3 categories of questions to answer:

- Decision-making: What decisions are available to the agent? What are the links among their perceptions, representations, and actions?
- Control: What are the hierarchical relationships among agents? How do they synchronize?
- Communication: What message do they send each other?

Multi-agent systems simplify problem-solving. They divide the necessary knowledge into subunits by associating an intelligent independent agent to each subunit and by coordinating the agents' activity. This theory can be applied to monitoring an industrial process [70]. The main applications for multi-agent systems are in telecommunicatins, the Internet and physical agents, such as robots [71].

In ecology, individual-based models (IBM) were developed in the 1980s. According to [72] there are two reasons for this: Firstly, the individual has to be taken into account because of the uniqueness. Secondly, the individual is situated and the interactions are local. There were a lot of studies published afterwards mainly in the ecological field with different approaches. [73], [74], [75]. Numberous ongoing applications can also be seen on the Web site of C.Reynolds [76]. Dedicated simulators also exist [77], [78]. A special issue of Ecological Modeling [79], [80] presented the conclusions after 10 years of development and use of IBM. Two ideas are expressed for the consolidation phase. The researchers investigate on the questions "how to describe the structure of a model and how to present the results?". The consolidation is also theoretical. Too many applications were presented without any concern about the generic nature of results. IBM was developed by ecologist trying to introduce the notion of the individual to understand the role of heterogeneity.

MAS are influenced by computer and social sciences. MAS emphasize the decision-making process of agents. An agent is not necessarily an individual and can represent any level of organisation. MAS are developing quickly in social sciences. It is associated with the methodological individualism where the individual is the elemenatary unit; also social groups, institutions can be agents, having their standards, contraints and rules expressed on a group level. Nowadays a lot of researchers in different areas of research use MAS for simulations. MAS platforms are available. Researchers in social science can use MAS to model decision-making and learning process, to study deeply and effectively the forms of organisation and interaction of various levels. In computer science we can use the concepts of social sciences on the behaviour of individuals as well as the interactions between agents (relation between organisations, institutions, hierarchies,..) and their envrionment. Interdisciplinary research can be strenghened and can give new input to various research fields, can offer new research opportunities and new research approaches.

4.2. Using MAS for innovation diffusion and technology transfer

Only few work have used MAS for studying the technology transfer, and none in the field of Green IT. Main works focus on the diffusion of innovation, and can be retrieved from a survey [81]. They mainly adress the marketing aspect and focus on targetting clients. However, their study is interesting to understand some aspects of technology transfer from this perspective, and to clarify the role of agent based systems approach (bottom-up) compared to top-down approach of aggregated models.

The top-down approaches start from a global view of the studied system. It tries to distinguish general mechanisms and to detail each one as subunits in a recursive way. In these approaches, we find the differential equations, and the system dynamics, among others.

The bottom-up approaches start by describing the behavioural rules of elementary entities, and we simulate the interactions of a large number of these entities to observe the global behaviour of the system. Here, two main approaches exist: Cellular Automata (CA) and Multi Agent Systems (MAS). While the Von Neumann Cellular Automata provide a provable formal model, it lacks some dynamism in particular for the topology of the links between the cells, and to differantiate the behaviour of each cell. As seen earlier, MAS allows for more dynamcity.

One of the pioneering work in innovation diffusion used a top-down approach. Originally, the Bass model [82] was fitted to the observational data of adoption rates, performs an aggregate description of the behaviour of potential decision makers in relation with the adoption or not of an innovation. It is a aggregated model based on mathematical formulation of diffusion. There is the set of deciders assumed to be homogeneous and totally connected. Bass charaterizes the diffusion of an innovation as a contagious process that is initiated by mass communications [83]. Managers benefit considerable from tools that help them to pre-estimate the market response to new products, provide model-based decision-support, and allow them to asses new product introduciton strategies. Aggregate models like the Bass model provide an empirical generalization based on a differential equation formulation. This support is limited, they are not made for what-if questions. These models do not take into account consumers' heterogeneity and the complex dynamics of social processes. Author of [83], proposing a model for the diffusion of products competing in a common market, supposes that each individual is influenced by all remaining decision makers. The basic assumption of the model is that at each point in time, potential buyers are exposed to two kinds of influence: an external influence (eg advertising campaigns) and an internal influence ("word-of mouth" interactions with adopters) [84]. The Bass model has the advantage of its simple application, constituting a description on a macro level that shows the observed global behaviour [85]. The lack of detail at a microscopic level turns it into a weak prediction instrument, restricting its application to analogies with similar known products [86].

To overcome the limitations of aggregate models agent-based modeling and simulation has been introduced. This bottom-up methodology models complex emergent phenomena. In agent based diffusion models the model element is the agent. Consumers' herogeneity, their social interactions and the decision making process can be modeled. The macro-level dynamics of the social system emerge dynamically from the aggregated individiual behaviour and interactions between agents. There are two main streams in the literature about agent-based models of innovation diffusion:

- Those aimed at theoretical insights and concerned with abstract and generic representations.
- Those concerned with the practical application of ABMs to provide forecasts, decision support, and policy analyses.

More studies of diffusion models at the micro level were done – with a focus on agent based models (ABMs) [81]. ABMs involve two complementary causes for innovation adoption:

- The individual evaluation of the advantages related to the adoption of the new product/technology
- The imitation of behaviour of close contacts which are considered as examples to follow by the decision maker.

ABMs have the advantage that the introduction of the social networks is possible. These social networks are the ways for interaction between the elements of the system [87]. In case of the diffusion of one new product or technology in a market, individuals, institutions or companies in ABMs must choose between two alternatives: to adopt or not to adopt. It was found that the before described social system can be obtained by using the analogy with the Ising statistic model [88]. The Ising model was originally developed in the field of physics. There the agents represent spins in a regular lattice. These spins can be in two positions: one in the direction of an external field and the other in the opposite direction. Each model can be influenced by its neighbours, generating a local field that induces the orientation of the spin.

Compared to the Ising model where interaction is limited to the nearest neighbours in a regular array, nowadays we may say that a social process of communication does not correspond to an interaction with the geographic proximity. So it is needed that the formalism is modified including irregular networks. This is the case in the "small worlds networks" (SWN) [89]. The different networks in the family of SWN are obtained by the variation of one parameter: the rewiring probability. The idea is to re-connect the agents with a regular network, according to the rewiring probability. If this probability is zero then there is a regular network, if it is one then there is a random network constructed. Different connection networks will be implemented in our model.

In the case in which two brands compete for one single market by using an agent-based cascade model two categories of agent-based diffusion models can be identified: [90], [91], [92]:

- Threshold models, in which agents adopt when a specified minimum number of neighbours have adopted
- Cascade model where the probability of adoption increases with the number of adopters in the neighbourhood, with an exponential mathematical dependency.

In our case, the probability of technology transfer will be influenced by the number of neighbours, more relevant to the cascade model than the threshold model. However, the behaviour of the agents could be modified to follow also the threshold model.

In [93] this formalism could be thought of as a threshold model, but applicable to possible-state options. In the proposed algorithm, agents have an implicit threshold that relates to the perceived effective utility of each of the potential choices. This threshold is a function of the differences of utility of the available options [94]. The utility changes with the behaviour of the neighbours. It means that the probability of adoption is dynamically modified in time for each agent, depending of the choices of their particular set of neighbours. Their main conclusions are the following: As the social network becomes more random, the market becomes saturated with product buyers more quickly. A quicker generation of innovators (through a bigger investment in publicity) modifies the curve of adoption of the product drastically, reaching as a consequence, in the best case of more than 70% of the market. The final proportion practically does not change with the modification of the topology of the social network.

In [95], authors study the diffusion in social networks. Diffusion in social networks has received considerable attention recently in many fields [96], [97], [98], [99]. The diffusion process in a social network includes diffusion actors that represent who will diffuse something (such as individuals, groups, or organisations in the society), diffusion medium representing the environment where the diffusion takes place, such as the connection characteristics (weak links, strong links) or the network structures, and diffusion content that represents what to diffuse. Diffusion can be described as the collective behaviour of a set of autonomous social actors for interacting on something in the social network [100]. Modelling diffusion as emerging phenomena from the interaction of individuals has attracted a substantial amount of activities of researchers. [101] [102]. Multiagent computing has already been widely envisioned to be a powerful paradigm for modelling the collective interactions of autonomous multientity systems [103] and social networks can be modelled as multiagents systems [100], [104]. The technology transfer can be seen from many perspectives as a diffusion in a social network. Indeed, the links between actors, represents ties in a social network in the same way.

In [105] Ma and Li presented one very simplified multi-agent system for technology transfer from universities to industries. They model only these two agents, with four possible states, from doing nothing up to participate actively to cooperation. In their finding, the cost of searching information (distance between company and university) and the search space (probability of finding a partner) are keys for a smooth technology transfer. While these two points are interesting, unfortunately this study is limited: only two kind of agents; innovation transfer is only based on a one-dimensional number that fluctuates between 0 and 100 for each agent; it does not take into account the funding and turnover of the partners to influence the direction. However, it is the only work closely related to technology transfer and multi-agent system so far.

4.3. Multi Agent System implementation

4.3.1. NetLogo as a multi-agent system

Several frameworks of multi agent systems exist in the literature and on-the-shelf, so we decided not to re-implement something that rather to rely on the existing tools. NetLogo is one such framework [106]. It simulates the evolution and interplay of agents in a complex world.

NetLogo was originally designed in 1999 [107] by Uri Wilenski, and is regularly updated since. It is used in many scientific fields: social science, economics, psychology, urban traffic, marketing spread, biology, chemistry, management to model complex behaviour over a given population, etc. It is also much used in classes to learn students the basis of programming. The last version of a book from the author is from 2015 [108].

The choice of NetLogo has been primarily motivated by three aspects: First the widespread adoption of this software makes its usage easy, with plenty of examples, tutorials and a large community for finding some tricks in the coding. Second, the programming language of Netlogo is simple, allowing to focus on the “what” rather than on the “how”, e.g. the coding of the objectives and the individual behaviours, and less on the programming language itself. Third, the behaviour of the model is reproducible, meaning under the same parameters all the agents behaviour and their scheduling will be exactly the same. This deterministic behaviour of the agents helps to construct scientifically sound experiments.

Finally, NetLogo provides a genuine GUI that allows, at small scale to see the evolution of the world and to adjust the behaviours of the different agents accordingly. Note that the GUI can be omitted so as to allow for large scale experiments or statistical analysis over several experiments: A java package can directly be called for such cases, and details will be provided in Chapter 5 about the experimental setup.

The implementation of the model has been designed using NetLogo 5.0.4. The software is free, open source under a GPL license. Altogether it represents about 2000 lines of codes.

In NetLogo, agents are turtles, links, patches or observers. The agents are members of a world that evolves step by step. Each agent evolves continuously.

- Turtles are the active agents, in a common sense. They will update their behaviour as a function of time, their environments, their position in the world, and their links.
- Links are agents that link two turtles. They evolve by themselves, as the other agents do.
- Patches are agents where turtles stand. The patches can influence the behaviour of its turtles, and vice-versa.
- Observers are agents that observe the system, reporting values and advancing the time.

In our work, we used intensively the turtles and the links but less the patches. It means the place a turtle stands will not impact much its behaviour. This could be changed as a future work. The following sections will detail which parameters were selected for the agents and their evolution other time.

4.3.2. Representing the actors

Following the analysis of chapter 2, I decided to model the following actors in this dissertation: research facilities (and their researchers), companies, TTOs, and funding agencies. Other actors may be added in the model to influence the world and the evolution of actors. It must be noted that the modularity of NetLogo allows each novel agent to be autonomously defined, and only links with other agents have to be set in case of model extension.

The goal of the work is to provide a first set of actors and parameters, and to study the influence of local and global settings in the evolution of the global system. For instance, the impact of the distributed funding, or the presence of TTOs, can be adjusted.

In this first section, we will define the parameters of the actors while the links between actors are defined in 4.3.3 and evolution of their parameters proposed in 4.3.5.

In NetLogo, the turtles are grouped in breeds. At the beginning of the code, one declares for instance:

```
breed [researchers researcher]
```

Extract 1: example of a breed of actors

To declare that a new breed is called researcher. Then operations can be executed on one individual researcher or on the group of researchers (see 4.3.5).

4.3.2.1. Researchers

A researcher has some attributes that translates in NetLogo to:

```
1   researchers-own[
2     permanent             ; true if a permanent researcher... false otherwise
3     my_contract_number    ; the contract number, if not permanent
4     ttl                   ; contract duration of non permanent researcher
5   ]
```

Extract 2: researchers attributes

A researcher can have a limited contract or a permanent one (line 2). In case of limited contract, the researcher is allocated to a contract (line 3) and the duration of that contract is a key feature. It can be continued in case the collaboration with an industrial partner continues, or it can be stopped. Each such researcher has therefore a time-to-live in the system (line 4).

Researchers are members of Research Facility. However this parameter is not including, since it can be deduced from the links a researcher have (see 4.4.3).

The main objective of researchers is to publish papers, and for this he tries to create new collaborations (to raise new funding, new partnerships) that will enable new publications at the end, increasing the reputation of the researcher. However, this attribute of one researcher is not embedded in the previous definition: Indeed, it is a common attribute to all turtles:

```
1   turtles-own[
2     action_period       ; the periodic setting that some turtles may follow
3     contract            ; total number of contracts
4     newcontract         ; new contracts since last tick
5     publication         ; total number of publications
6     newpublication      ; new publications since last tick
7     itr_cooling         ; interest for new cooling technologies
8     itr_virtual         ; interest for virtualization techs
9     itr_cloud           ; interest for cloud techs
10    running_contract    ; number of current running contract
11  ]
```

Extract 3: turtles attributes, common to all actors

Each turtle will have a number of publications, a number of new publications since last evolution, the number of contracts and of new contracts. When some of these attributes will be updated per agent, others will be computed as aggregation of values from individual agents. For instance, the number of publications of one research facility is the sum of the publications of its researchers.

Line 7, 8 and 9 represent the interests of the turtles for technologies. For the sake of understanding, only three technologies chosen from the survey have been selected. Line 10 gives the number of currently running contracts.

Finally, each turtle can evolve either at each time step, or at periodic rate (line 2).

4.3.2.2. Research Facilities

A research facility is grouping a number of researchers, and is responsible for the contracts and the evolution of the collaborations.

```
1   researchfacilities-own [
2     turnover          ; amount of money available
3     funding_research  ; amount of money as incentives to researchers
4     rstaff            ; staff dedicated to research
5     tstaff            ; technical staff
6     astaff            ; administrative staff
7     research-output   ; accumulated research output
8     reputation        ; reputation of a research facility
9     my_history        ; history of publications and contracts
10    mytto             ; the TTO a research facility may be linked to
11  ]
```

Extract 4: research facility attributes

A research facility will have a turnover (line 2), which represents the funding received by the university so far so conduce research, either by projects (involving several partners) or direct collaboration (one to one with one company) (see 4.3.3 for details). It also has an amount of money dedicated to funding publications and serves as incentives for researchers to make publications (line 3).

The research staff (line 4) is simply the number of researchers attached with this research facility, while the technical staff and administrative staff are also attributes (line 5 and 6). Research output (line 7) represents the cumulative research output of the researchers.

The main objective of a research facility is to raise its reputation. Reputation of a research facility (line 8) is based on the history of its publications and contracts (line 9).
Finally a research facility is potentially attached to a TTO (line 10). This may or may not happen, a TTO is not compulsory.

One may notice that the link between a research facility and its researchers, or between a research facility and a company is not listed in the attribute. Indeed, in NetLogo, this is setup thanks to the links that are established between the turtles (see 4.3.3).

4.3.2.3. Companies

A company have similar attributes than a research facility and is therefore not detailed here. The main difference is that a company has no attribute for a link with one TTO and we did not model its reputation, since its main objective is to increase its turnover.

4.3.2.4. TTOs

A TTO has three attributes: its turnover, the number of transactions it had held so far, and the percentage it takes on every contract signed.

4.3.2.5. Funding Agencies

We decided not to explicitly model a funding agency as an agent in our system. Its behaviour is very simple for the moment (e.g. distributing funding regularly), and it did not deserve a more complex agent and behavioural schema. However in case one would like to extend the model, it can be turned easily into a new breed, therefore as a new kind of turtle.

In NetLogo, global variables are set in the following manner (other global variables not related with funding agencies are omitted here):

```
1  globals [
2    globally_funded          ; the total funds distributed to projects
3    funding_agencies ;   the rhythm funding agencies will fund new projects
4    funding_agencies_fund    ; the amount to distribute at each call
5    max_funding              ; the maximum funding
6    min_funding              ; the minimum funding
7  ]
```

Extract 5: Global variables of the model

We record the total amount distributed to the projects (line 2). The rhythm of funding (line 3) is set for one experiment, while the amount to distribute to each call (line 4) is computing for each call between an upper and a lower bound (line 5, 6).

4.3.3. Representing the links

The links identified in Chapter 3 are represented by links in NetLogo. Links can be of different type, and have their own behaviour.

We declared 6 types of links:

```
1  undirected-link-breed [belongto-links belongto-link]
2  undirected-link-breed [project-links project-link]
3  undirected-link-breed [partnership-links partnership-link]
4  undirected-link-breed [regular-links regular-link]
5  undirected-link-breed [ttolink-links ttolink-link]
6  undirected-link-breed [ttopartner-links ttopartner-link]
```

Extract 6: Declared links

The first type of link represents, for one researcher the research facility it belongs to (line 1). As links are not directed, a research facility will also be able to know who its researchers are. Such a link is active until the researcher quit or is fired (at the end of a project for instance).

Partnerships (line 3) and projects (line 2) are represented by links. They have a duration related to the project duration. A difference is that a partnership link is set between a company and one research facility only, and may be kept at the end of its duration, depending on the interest of the partners to pursue this collaboration. While a project link will finish after the signed contract ends, and a project involves at least 3 parties.

Regular links (line 4) represent the informal contacts between researchers and between researchers and companies.

A research facility may be tied to a TTO (line 5). If a TTO exist, it will keep track of the partnerships signed in the form of links (line 6).

All links share the same following definition (note that some attributes have a meaning only for certain links):

```
1   links-own[
2     initial_investment      ; initial investment for this link
3     strength                ; strength of this link
4     gcontract               ; generated contracts
5     gturnover               ; generated turnover
6     link_ttl                ; holds the links time to live
7     rlstaff          ; number of dedicated people from research facilities
8     clstaff          ; number of people dedicated people from companies
9     tlstaff           ; number of technical people
10    alstaff           ; number of administrative people
11    contract_number   ; the number of the contract that set up the link
12  ]
```

Extract 7: Links' attributes

In case of a project or collaboration, the partners may invest initially in the collaboration (for companies, line 2). Each collaboration link will generate turnover (line 5) and contracts (line 4). The strength of the link (line 3) represents the potential for continuing a partnership.

The time to live of a link is representing the duration of a project or partnership (line 6).

The staff working on a relationship is also represented (line 7-10). Finally the contract number that generated this link is kept so that all links related to the same contract can be easily retrieved (all partners in a project, all researchers linked to a project, …).

Several topologies of links can be initiated at the beginning of the simulation, so that already contacts and collaborations exist beforehand. Three networks have been implemented: scalefree, random and smallworld, with different densities. They exhibit different ways of connecting initially turtles in the world and may impact the technology transfer (in terms of speed, results, etc).

4.3.4. Initialisation of the system

The multi-agent-system is initialized in three ways:

- First there are a number of global variables that are set by the user (e.g. number of turtles of each kind, minimum and maximum funding, the probability for a collaboration to be profitable, the probability for a project to get funded, the initial networking of the agents, etc.). These settings are arbitrary and will allow the user to test (see Chapter 5) several possibilities and behaviours.
- Second, some variables are set within values coming from the survey and from the literature review. For instance the interests in technologies, the average number of researchers per research facility, the staff for helping research (administrative and technical), the presence of a TTO for a research facility, etc.

- Third, some variables are set randomly (e.g. the funding at each funding step for projects, the choices of partners in collaborations or projects, the dissemination of the research, etc.).

4.3.5. Evolution of the system

In NetLogo, a procedure (typically the *go* procedure) is repeatedly executed, at every 'tick'. A 'tick' in NetLogo represents any interval of time, a timestep. We decided for our model that one tick represents one day. One could argue that one day is too short to see the evolution of actors like researchers, companies, etc. However thanks to the possibility of the simulator, any action is not taken at every tick, but can be executed every n ticks. Also, with such a setting, as we want the system to evolve enough during time, we have 7280 steps (with a limit after 20 years). With a tick representing 3 months, we would have had only 80 steps for the same period, which we think is not enough to show the dynamic of the system.

At every tick, the go procedure can ask each turtle to update, meaning each turtle will have its own and unique personal behaviour.

Of course, if there is no randomness in the behaviour of all turtles of a certain breed (for instance all researchers), they will all act in the same way (for instance make contact with the same other researchers or publish the same amount of results).

The code for a step of evolvement of the system is given here:

```
1   to go
2     if ticks >= 7280 [ stop ]
3     if (ticks mod funding_agencies = 0) [
4         funding_agencies_fund = (10*max_funding + random (min_funding)) ]
5
6     ask researchers [ update-researcher ]
7     ask ttos [ update-tto ]
8     ask companies [ update-company ]
9     ask researchfacilities [ update-researchfacility ]
10
11    ask patches [ update-color-patch ]
12    ask links [ update-links ]
13    ask turtles [ update-spi ]
14
15    tick
16  end
```

Algorithm 1: Day-by-day algorithm

The simulation lasts for 20 years (line 2). Funding agencies are funding research projects at a regular pace (line 3), and the amount to distribute to projects is set (line 4).

Then a demand to each agent is launched (line 6-13) so that every agent will update its attributes with its specific logic. Remember here that links and patches are also agents in NetLogo. Note also that all turtles can be asked to make a specific process (line 13).

Finally, the evolution goes to the next step (line 15).

Please note that this code extract is simplified in order to remove all aspects related to the GUI and to keep only the logic of the evolution.

As it can be seen, each agent will be asked to update its behaviour. Let's have a look now on the evolution of the agents. Instead of putting code extract, we will present the evolution of the agent in algorithms. The code extract are sometimes a bit difficult to read, the logic is more visible as algorithms. Their NetLogo code can be retrieved in Annex 3.

4.3.5.1. Evolution of the researchers

The evolution of the researchers must allow them to improve their own objective. As discussed earlier this objective is the number of publications. The number of publications one researcher can produce is based on its network, meaning the other researchers in research facilities or companies that he knows, in order to increase his knowledge and raise new ideas to get published.

The corresponding algorithm can be seen in Algorithm 2 below.

```
1   if (not permanent) then ttl = ttl – 1
2   if (ttl <= 0) then die
3   employer = research facility that employs the researcher
4   num = number of regular neighbours
5   newpublication = 0
6   repeat num [
7        money = funding_research of employer
8        if (random-float 1.0 < (0.20 * 1 / 90) and money > 1000 ) then
9          [
10           newpublication = newpublication + 1
11           ask employer [ funding_research = funding_research – 1000]
12             ]
13  ]
14  publication = publication + newpublication
15  update-interests
16  ask my-regular-links [ if (random-float 1 <= 1 / 180 ) then die ]
17  if ( num < max_link_per_researcher ) then
18  [
19   bonus = num / (max_link_per_researcher * 20)
20    if (employer has new contracts) then [ bonus = bonus + 0.05 ]
21    if (funding_research of employer > 100000) then [ bonus=bonus + 0.05 ]
22    if (random-float 1 <= (1 / 90) + bonus)) [
23        r = random 100
24        if ( r < 50 ) then [ partner = partner-choice ]
25        else if ( r < 75) then [ partner = tto-choice ]
26        else [  partner = one-of find-neighbors-of-neighbors ]
27        make-link partner "regular"
28      ]
29  ]
```

Algorithm 2: update-researcher

All non-permanent researchers have their time-to-live decrease by 1 day (line 1). When it reaches 0, then this researcher is finishing its existence in the model (line 2).

All researchers may publish with their contacts, meaning their regular links (line 3-14). However, we set that it might occur in average once every 3 months (90 days) with a 20% probability for each link, and when the funding of the research facility is enough. This last point simulates the cost for the contact (in- and out-bound travels) as well as the cost for publication itself).

The interests of one researcher for technologies may change during its lifetime (line 15). The algorithm to update the interests of researchers (and companies, the same algorithm holds for both) is depicted in Algorithm 3, for one interest in general. Each particular interests depicted in Extract 2 (lines 7, 8, and 9) follows the same pattern.

Some links may disappear after a certain time, due to lost contacts (line 16), in average every 6 months (180 days).

Some new contacts may be constructed (line 17-29), if one doesn't have already too many contacts (line 17).

The probability of having new contact is increased by the number of existing contacts (line 19), if the research facility the researcher belongs to get new contracts (line 20) and if the research facility investment for new research is large enough (line 21). Then a contact is created every 3 months in average (90 days, if the probability is not increased).

The contact is made randomly with three cases, where the probability of selecting one partner or another comes from the survey (see Section 2.2):

- In 50% of the cases (line 24), the choice is made by the researcher himself, among all possible contacts, favouring (the probability is higher) the ones with the best compatibility with himself.

The compatibility function is defined as the distance in knowledge space between two actors, i.e. a weighted distance of the technologies' interest of the partners, where the weights come from the survey (see 2.2.5). The corresponding function is given in Extract 8, for the three interests chosen. It returns a percentage of compatibility, and takes as input two turtles:

```
to-report compatibility [ turt1 turt2 ]
  report 1/100 *
    (21.2 * (100 - abs ([itr_cooling] of turt1 - [itr_cooling] of turt2))
   + 39.4 * (100 - abs ([itr_virtual] of turt1 - [itr_virtual] of turt2))
   + 39.4 * (100 - abs ([itr_cloud] of turt1 - [itr_cloud] of turt2)))
end
```

Extract 8: Compatibility Function

This case represents researchers meeting in conferences and professional salons. And the compatibility describes that researchers are more keen to collaborate with others having similar interests.

- In 25% of the cases (line 25), if the research facility of the researcher has a TTO, then the TTO provides one choice of partner for the researcher among all the ones it knows. This reflects the fact that some contacts are initiated by TTOs.
- In 25% of the cases, the researcher will find new contacts from the neighbours of its neighbours, meaning using actively his social network.

```
1   b1 = 0
2   ne = my regular neighbours
3   if (ne is not empty) [
4      m = max [ interest] of ne
5      if (interest < m) then  [ b1 = (m - interest) / (1000 + interest) ]
6   ]
7   ne = partnership and project neighbours of my research facility
8   if (ne is not empty) [
9      m = min [ interest ] of ne
10     if (interest < m) then [ b1 = b1 + (m - interest) / (1000 + interest) ]
11  ]
12  interest = interest + b1
13  interest = interest - random-float 0.001 * interest
```

Algorithm 3: update-interests

Algorithm 3 updates the interests of one researcher or company based on his neighbours. Line 2-6 handles the change in interest one can have due to its direct regular neighbours. The interest is updated as a function of the maximum interest in one researcher neighbourhood, so that the researcher might want to go towards this great interest in priority. This reflects the exchange of interests between parties and the discussion in research that may involve as reaction for some researchers a change in interest. However this change is slow, as it would take 1000 days to replace the current interest if only this link would exist.

Line 7-11 reflects the impact of the research facility the researcher belongs to, in taking into account the projects and collaboration it has. In this case, the researcher compares itself with the minimum interests among the group, so that he can move towards this interest slowly.

The researcher interest is updated potentially thanks to its neighbourhood (line 12).

Finally, the interest is decreasing slowing each day, the interest shading with time (line 13) to finally disappear in a minimum of 1000 days.

It must be noted here that the curve of interests could follow the Gartner hype curve, such as the one on Figure 5 showing the changes of interests in the Cloud technology (as of 2012). This would allow for researchers and companies not to follow the same function and not to react in the same manner to change of time. This will be left as future works.

Figure 5: Hype of Cloud Computing, 2012, Source: Gartner

4.3.5.2. Evolution of the research facilities

The research facilities, besides having researchers, care for its reputation. To reach the objective of a good reputation, it will try to contract with partners, in order to get funding to fund research. The algorithm of its evolution is given in Algorithm 4.

```
1   newcontract = 0
2   my_r  = set of researchers belonging to myself
3   rstaff = count my_r
4   interest = mean [interest] of my_r
5   research-output = research-output + sum [newpublication] of my_r
6   update-reputation
7
8   my_np = subset of my_r with [ permanent = false]
9   if (turnover < critical) then [ ask one-of my_np [ die ] ]
10  turnover = turnover - ( (count my_np) * cost_per_day )
11
12  if (ticks mod action_period = 0  and turnover > min_turnover) then [
13   if (count my_np < (count my_r * 4) ) then [
14       hatch-researchers [ ttl = 365 ]
15       ]
16   if (funding_research < 100000) then [
17     funding_research  = funding_research + turnover * incentive / 100
18      turnover = turnover - turnover * incentive / 100
19    ]
20  ]
21  if (ticks mod funding_agencies = 0) [ create-project ]
```

Algorithm 4: update-researchfacility

First, each day, the number of contracts is reset (line 1) and some internal attributes of the research facility are updated: its researchers (line 2 and 3), where rstaff is the number of researchers belonging to the research facility. The interest of the research facility is computed as the mean of the interests of its researchers (line 4), and the research output is accumulating their publications (line 5). The reputation of the research facility is computed and updated (line

6): Currently, it is computed as the sum of the last `RF_history_size` (where `RF_history_size` is a global variable) of publications and contracts of the research facility, thanks to the history of the researcher facility which is also updated in this function.

The research facility deals with its non-permanent researchers (line 8), possibly firing one of them if the money run below a `critical` global value (line 9). The turnover of the research facility is decreased by the salaries of the non-permanent researchers (line 10). In the model, the permanent researchers have no cost, and we suppose this is dealt transparently.

Then the research facility may act regularly, if it turns out that it has enough money (line 12). Its possibilities are:

- To enrol a new non-permanent researcher with a one year contract, when the number of non-permanent is not too large compared to the number of permanent ones. (Lines 13-15). We set here that there can’t be more than 4 times more non-permanent than permanent researchers in a research facility.
- To raise the funding dedicated to researchers (line 16-19), that represents an incentive for the researchers to find contacts and to publish (see Algorithm 2).

Finally, when the funding agencies are raising some calls, the research facility tries to construct a project with partners (line 21). The project construction is a complex phase and is depicted in Algorithm 5.

```
if (funding_agencies_fund < min_funding) then [ stop ]
project_funding = min_funding + random max_funding
my_r = set of my researchers
if (not any? my_r) then [ stop ]
free = count my_r with [ permanent = true ] - running_contracts
if (free <= 0) then [ stop ]

neighborhood = research facilities and companies known by my researchers and my tto (if existing)
neighborhood = subset of neighborhood with [
 rstaff >= 1 for research facilities
 cstaff >= 1 and funding_research > project_funding / 3 for companies
]
n = min (4, random (count neighborhood))
partners = my-n-of n neighborhood

n = 1 + random 2
nbp = count partners + n
potential = set of all research facilities and companies
potential = subset of potential with [
 rstaff >= 1 for research facilities
 cstaff >= 1 and funding_research > project_funding/nbp for companies
]
partners = partners + my-n-of n potential
nbp = count partners + 1
if (nbp < 3 or no-company-in? partners) then [ stop ]
if (random 100 > call_success) then [ stop ]

duration = 24 + random 24
funding_agencies_fund = funding_agencies_fund - project_funding
```

```

      myshare = 1.2 * project_funding / nbp
      project_funding = project_funding - myshare
      contract = contract + 1
      running_contracts = running_contracts + 1
      newcontract = newcontract + 1
      if (mytto != nobody) [
        myshare = (1 - [ percentage ] of mytto) * myshare
        ask mytto [ turnover = turnover + percentage * myshare ]
        ]
      turnover = turnover + myshare

      non-staff = 0.5
      r = 12 * round (myshare * non-staff) / (cost_per_day * 365)
      newbies = enrol-newbies r
      ask n-of (newbies/4) my_r [ make-link one-of partners "regular" ]

      foreach partner in partners [
        make-link partner "project"
        ask project-link-with partner[
         contract_number = gcontract_number
         rlstaff = rlstaff + newbies
         link_ttl = duration * 30
        ]
        ask mytto [
          if (not ttopartner-link-neighbor? partner) [ make-link partner "ttopartner" ]
          ask ttopartner-link-with partner [ link_ttl = duration * 2 * 30 ]
        ]
      ]
      ask partners [
        newcontract = newcontract + 1
        running_contracts = running_contracts + 1
        contract = contract + 1
        myshare = project_funding / (nbp - 1)
        if (is-researchfacility?) then [
            create-project-with myself myshare ]
        else [
          funding_research = funding_research + myshare
          cashflow = 2 * myshare
          cstaff = cstaff - 1
          funding_research = funding_research - cashflow
          r = 12 * round (myshare * non-staff) / ( cost_per_day * 365 )
          newbies = enrol-newbies r
          cstaff = cstaff - newbies
          ask link-with myself [
            initial_investment = cashflow
            gturnover = gturnover - cashflow
            clstaff = newbies * 2 + 1
          ]
        ]
       ]
```

81	gcontract_number gcontract_number + 1

Algorithm 5: create-project

First, the research facility checks if some funding is still available (line 1), and if yes, which amount could be distributed if the project goes through (line 2). A research facility without researchers can't build project (lines 3-4), and the researchers need to be available: The number of running contracts must not exceed the number of permanent researchers, so that each is responsible locally at most for one project (lines 5-6).

The research facility then searches to construct a consortium of partners, first with already known partners (lines 8-14), plus adding randomly new unknown partners (lines 16-23). The partners are chosen, in both cases, within the research facilities with research staff, and companies with research staff and enough own funding to participate in the project.

One particularly important function is the `my-n-of` function (lines 14 and 23) that helps choosing some partners randomly, favouring the ones with the most compatibility first. Other criteria can be investigated for this choice, as we will see in Chapter 5 when the criteria will be related to a measure of the sustainability of a partner.

The number of partners is finally known and if it is too small, the project is abandoned (lines 24-25). Still a chance exists that it is not successful, which is controlled by the global variable `call_success` (line 26).

Once successful, the project has duration in months (between 2 and 4 years, line 28), and the share of each partner is calculated, starting by the one of the initiator of the project (having a bonus of 20%, line 31). If the research facility is linked with a TTO, this one gets a percentage of the funding (lines 36-39). Finally the research facility gets the funding (line 40).

To conduct the project, the research facility can employ new staff (Postdoc, Engineer, PhD.), within half the allocated budget (lines 42-44): We consider that the other half is for administrative purpose, equipment, travels and the like. The function `enrol-newbies` (not detailed here) ensures that the number of newbies hired is less than four times the number of permanent researchers. Then the implied researchers of the research facility can randomly make contact with the different partners of the project (line 45).

The research facility creates actually the links for the project (lines 47-58), potentially informing the TTO so that it also creates its own links. Note that we consider the TTO to keep a trace of the partners for twice the duration of the project itself. This ends the research facility role in the project construction.

The rest of the algorithm exhibits the impact of this project at the partners' side. For a partner being a research facility, the function `create-project-with` is having a similar behaviour than already described (lines 36-45) and is not repeated here for clarity. For a partner being a company, the impact is different: A company is asked to invest initially in the project, being rarely funded 100% (line 68). At least one staff must work on the project (line 69) and the company invest in this project (line 70). Like a research facility, a company may hire some researchers (line 71-72), the difference being that we consider that the number of newbies in a company can't exceed the number of research staff in the company, which is finally put on the project (line 73). The link representing the project keeps in memory the initial investment and the staff dedicated to the project from the company (line 74-78).

Finally, the number of contracts is increased by one (line 81), a new project started.

Note that this algorithm is simplified here, omitting the corner cases where some partner sets are empty.

4.3.5.3. Evolution of the companies

The companies follow the algorithm described in Algorithm 6.

```
1   newcontract = 0
2   update-interests
3   if (ticks mod 30 = 0) [
4      if ( turnover > min_turnover ) [
5        funding_research = funding_research + turnover / 10
6        turnover = turnover - turnover / 10
7      ]
8      else [
9         turnover = turnover + 0.9 * funding_research
10        funding_research = 0.1 * funding_research
11     ]
12   ]
13  if (ticks mod action_period = 0) then [ create-partnership ]
```

Algorithm 6: update-company

A company updates its interest (line 2), just like the researchers (see Algorithm 3). Then every month (line 3), if the turnover of the company is sufficient (defined by the global variable `min_turnover`), it will invest some funds for research (lines 4-7), otherwise it will transfer all money dedicated to research to its turnover (lines 8-11): This rollback mechanism is set so as a company can't have a negative turnover while still investing on research (mostly forbidden by funding agencies).

At regular time, the company can initiate a direct partnership with a research facility, a one-to-one relationship (line 13). The algorithm related to the `create-partnership` function is very similar to the previous Algorithm 5: create-project, therefore we will not detail it here. The main differences are the following:

- The company needs a minimum amount in its research fund, and its turnover must be above the minimum turnover.
- The duration of the partnership is between 12 and 36 months.
- The company searches partners among the research facilities that it has projects with, its network of researchers, and all TTOs existing in the world.
- The company can't start a new partnership with a research facility with which it already cooperates.
- The company and the selected partner can randomly build the partnership if their interests are compatible enough.
- The funding is coming from the company, that invests locally half of it and the same amount is given to the research facility.

4.3.5.4. Evolution of the TTOs

The TTOs evolution is controlled by Algorithm 7:

```
1 if (ticks mod action_period = 0 ) then [
2     let myRF = my research facility
3     let help = turnover * tto_to_RF_back_percentage / 100
4     set turnover = turnover - help
5     ask myRF [
6       set funding_research = funding_research + help
7     ]
8 ]
```

Algorithm 7: update-tto

On a regular basis, the TTO will return an amount of money to its research facility. The amount is determined by its turnover and the globally defined `tto_to_RF_back_percentage` variable (line 3). The TTO turnover is reduced (line 4) while the research facility funding for research is increased (lines 5-7).

4.3.5.5. Evolution of the links

In NetLogo, links are also agents, therefore they can evolve independently during the experiments. Some links will not evolve, like the ones between a TTO and its research facility, or the one linking one permanent researcher with its research facility.

Other links will evolve, in particular the ones built during project or partnership construction, as described earlier.

The Algorithm 8 details the evolution of the links.

```
if (link-type = "ttopartner") then [
 link_ttl = link_ttl - 1
 if (link_ttl = 0) then [ die stop ]
]
if (link-type = "project") [
 link_ttl = link_ttl - 1
 if (link_ttl = 0) then [
    number = contract_number
    links-impacted = project-links with [ contract_number=number ]
    b = 0
    foreach agent in links-impacted [
        running_contracts = running_contracts - 1
        if (is-company?) then  [
            cstaff = cstaff + round ([clstaff] of link-with other-end / 2)
            turnover = turnover + [initial_investment] of agent
            if (random 100 <= conversion) then
                b = b + ([initial_investment] of agent * (1 + random-float
3))
        ]
    ]
    if (b = 0) then [ stop ]
```

```
21          nbp = count agents in links-impacted
22          foreach agent in links-impacted [
23            ask agent [ set turnover = turnover + b / nbp ]
24          ]
25          kill-all-links in links-impacted
26        ]
27       if (link-type = "partnership") then [
28        link_ttl = link_ttl - 1
29        if (gturnover > 0 ) then [ link_ttl = link_ttl + 1 ]
30        if (random 100 - strength <= conversion) then [
31          link_ttl = (12 + random 25)
32          benefit = (initial_investment * (1 + (random-float 3)))
33          gturnover = gturnover + benefit
34          strength = min (99, 1 + compatibility end1 end2 / 100)
35          ask both-ends [
36          if (is-company?) then [
37             turnover = turnover + benefit
38            cashflow = min (funding_research, [initial_investment] of myself +
   (random ([gturnover] of myself) * random (0.25 + 0.25 * [strength] of myself /
   10) ))
39            funding_research = funding_research - cashflow
40             ask other-end [
41                  turnover = turnover + cashflow
42             ]
43          ]
44          else [
45              my_r = set of my researchers
46              cn = [contract_number] of myself
47              np = my_r with [not permanent and my_contract_number = cn]
48              ask np [ ttl = [link_ttl] of link-with myself ]
49          ]
50          ]
51        if (link_ttl <= 0) then [
52         ask both-ends [
53          set running_contracts = running_contracts - 1
54          if (is-company?) then [
55            set cstaff = cstaff + round ([clstaff] of link-with other-end / 2)
56          ]
57          die
58        ]
59       ]
```

Algorithm 8: link evolution

There are 3 kinds of links that will evolve during time. First are the links the TTOs have with partners. These will disappear after their time-to-live (lines 1-4).

Second are the links related to one project. When such a link reaches its time to live, it is the end of the project (lines 5-7). In such case, both sides of the link (meaning either the research facility or one of its partner – research facility or company) have to close the contract. For a company (lines 11-19) the staff is returning to the company, and it retrieves its initial investment (line 15), and a bonus in case the contract was profitable is computed (lines 16-18), meaning it generated some benefits (in the form of patent for instance). This probability is handled by the global variable `conversion`. As it was a collaborative project, all partners may benefit from this benefit, as well as they may also generate profits themselves. The benefits are then shared between all members of the project (lines 20-24). Then the links related to this project disappear (line 25). Please note that if TTO exists, it gets part of the benefit (omitted in this algorithm for clarity).

Third are the links related to a direct partnership. If this partnership generated some revenue, its time-to-live is increased (line 29) so that it will not disappear immediately. The success of the partnership is checked (line 30), including the strength of the link between partners. This strength is computed at each partnership as the compatibility between the two partners (line 34). If it was a partnership with success the partnership is extended (line 31), the benefit computed (line 32), the benefit of this link updated (line 30) as well as its strength (line 34). Then for both partners the partnership will be continued: the company collects its benefit (line 37), and will need to invest again (lines 38-41). The new investment is related to the initial one, to the generated benefit of this collaboration, and by the strength of the link, and can't surpass the funds dedicated to research at the company. The research facility collects its benefit, possibly through a TTO (omitted here), and extends the contract duration of the non-permanent researchers working on this partnership accordingly (lines 45-48). Finally when the time to live of the link is reached, the partnership is discontinued and the staff working in the company quit the project and returns to the company. It must be noted that the research staff of the research facilities is not handled in the same way, and there is no need to stop their contracts, since they will disappear by themselves (see Algorithm 2).

4.4. Conclusion

In this chapter 4, we reviewed the literature on Multi-Agent-Systems and in particular its usage in technology transfer, highlighting the main characteristics of such a system. We presented a model for technology transfer described in NetLogo, a well-known platform for designing and experimenting with MAS. The algorithms driving the autonomous behaviour of the selected actors (researchers, research facilities, companies and TTOs) have been described.

Up to now, the link with Green IT is loose in this modelling. Only the notion of interests are linked with this field, which could be changed for another one easily. This makes this modelling agnostic of the target field: This can be seen as a strength of the model, but also may lead to miss the point of studying the technology transfer in the particular field of Green IT. Two aspects will have to be studied: How does the model proposed behave in terms of Green IT, and how to adapt it so that the Green IT impact is included in the decision phases of the agents. These will be the challenges of Chapter 5.

Chapter 5. Integrating Green IT in the model

Chapter 5 is dedicated to two aspects: First, it will link the model with Green IT and I will propose a definition of a computable sustainability performance indicator (SPI). Second, I will compare different scenarios on a number of determined metrics representing the objectives of the different actors as well as the evolution of the SPI. I will finally integrate the SPI in the model and compare its evolution with the previous cases.

5.1. Sustainability Indicator

The previously presented multi-agent-system is loosely coupled with Green IT, as explained earlier. The question of “how to evaluate it?” comes to the question of “In which topic to evaluate it?”, and to the subsequent question: “How to evaluate it in this field?”.

It would be perfect if one general commonly agreed definition of Green IT would exist, but as explained in Chapter 2, it is not the case. Our definition given in Chapter 2 links Green IT and sustainability, so as it represents the movement towards this. Therefore, simply looking at the sustainability of the actors and their evolution during their lifetime would help to derive if a decision has a positive or negative impact on Green IT.

Still, a globally agreed definition of sustainability is difficult to find. During the last years the development of sustainability indicators was a major interest on the regional, national but also international level. It is important to know that sustainability indicators have to be set by the members of the society to be accepted and cannot be defined from outside.

The [109] gave a definition of sustainability and stated a link between environment and development: development which meets the needs of the present without compromising the ability of future generations to meet their own needs

Companies have to be more aware about sustainability as in the society the usage of resources nowadays is discussed in terms of the future of next generations. Therefore a long-term view on economy and societal issues is important. Additionally sustainability indicators have to be developed for each single topic, e.g.: cities, production, environment, etc.

Indicators are an effective way of packaging and conveying performance information to target user groups. They serve to summarise large or complex sets of performance-related data in a manageable quantitative or qualitative form. The reason for the development of indicators is to generate useful information for different audiences as companies, policy-makers, governments, etc.

Aims for examination of indicators may vary between early warning, assessment of trends, competitor benchmarking, identifying options for improvement, assisting external stakeholders in understanding and reacting to performance trends

A critical point of view says that sustainability indicators only reflect the status at a certain time but they do not represent a movement. Therefore no direction can be indicated, but only a status.

5.2. Computing a sustainability performance indicator

Composing with the complexity of the previous observed definition, we can still commonly agree that the three dimensions of sustainability (ecological, economic and societal) must appear in any indicator representing the sustainability of a system.

Our choice has been to compute the sustainability of the actors of the system, and to estimate the sustainability as the mean of their sustainability. This is controversial, but remember that we do not aim at providing a definitive value for sustainability but we are interested in its evolution during time. The gradient of this evolution is our observable impact of the decisions taken on the system, meaning the decisions each of the actors can individually take.

We will now relate the different aspects of sustainability with the objectives of the different actors in the system, and we outline their evolution. Remember that each aspect is evaluated for each of the actors.

5.2.1. Ecological aspect

The ecological aspect is reflected at one actor by 4 different values, based on the awareness of Green IT and the three R (reduce, reuse, recycle).

In detail:

- awareness: It represents the awareness of Green IT solutions. It increases with the number of publications and the number of contracts one has. It decreases with time, since the awareness of solutions fades without contacts.
- reduce: It represents the reduction of energy consumption. It increases with the number of contracts with a probability p1.
- reuse: It represents the reuse of materials. It increases with the number of contracts with a probability p2.
- recycle: It represents the recycling of materials to new products. It increases with the number of contracts with a probability p3.

We have $p1 + p2 + p3 = 1$, meaning that an action is taken on one of the three R, in average. The three "R"s values decrease when the number of employees increases, since more employees means more IT.

5.2.2. Societal aspect

The societal aspect is reflected at one actor by 5 different values enforcing the role of one actor in the society at large:

- greenemployement: It represents the number of employees that are hired to work on Green IT. It increases with contracts (newbies are recruited), and decreases at the end of contracts. It also increases spontaneously when the money for research is high enough at research facility.
- awarenessconsumption: It represents for the society the awareness of energy consumption of IT. This increases with the number of publications and contracts, with more weights for publications than contracts (0.8 / 0.2). It decreases with time as the interest in energy consumption fades if not reactivated.
- rethink: It represents the capacity of one actor to rethink its strategy in terms of Green IT. It increases with the number of publications and researchers: more researchers and

more contacts allow for more brainstorming. It decreases with the number of contracts, since researchers are then dedicated to specific projects, with less freedom of thoughts.

- image: It represents the image of the actor in the society. This image will increase with contracts and publications (and possibly communication strategy). It fades with time.
- standardisationinfluence: It represents the influence one actor will have on the standardisation bodies. It follows the number of employees and its turnover (the size of the actor) and additionally decreases with time.

5.2.3. Economic Aspect

The economic aspect is linked to 3 different values:

- economicalimpact: It represents the economic impact of Green IT solutions. It follows the number of successful running contracts.
- turnover: It represents the turnover of the actor, increasing within contracts. It decreases with new investments and the funding of research.
- attraction: It represents the potential for attracting investors for the actor. It increases with the image of the actor and its turnover and decreases with time, as a function of the image.

5.2.4. Sustainability Performance Indicator

Aggregating values from these different dimensions finally leads to a sustainability performance indicator (or SPI). The question of aggregating values is always complex, and in this case it is even worse since the dimensions of the three aspects are different: percentage, absolute values, etc. Hence we first normalized all values to their maximum.

To compute the SPI, we considered that each of the previously explained elements might not have the same weights, leading to the following equations:

ecological = awareness * w_awareness + reduceenergy * w_reduceenergy + reuse * w_reuse + recycle * w_recycle (Eq 1)

societal = greenemployment * w_greenemployment + awarenessconsumption * w_awarenessconsumption + rethink * w_rethink + image * w_image + standardisationinfluence * w_standardisationinfluence (Eq 2)

economical = economicalimpact * w_economicalimpact + turnover * w_turnoverSPI + attraction * w_attraction (Eq 3)

spi = w_ecological * ecological + w_economical * economical + w_societal * societal (Eq 4)

In our implementation, the weights are given in Table 9:

SPI weights	w_ecological	0.33	The weights for the three aspects are equal so as an impact on ecology is the same as an impact on economy or societal, and vice-versa
	w_economical	0.33	
	w_societal	0.33	
Ecological weights	w_awareness	0.1	
	w_reduceenergy	0.3	
	w_reuse	0.3	
	w_recycle	0.3	
Societal weights	w_greenemployment	0.3	
	w_awarenessconsumption	0.15	
	w_image	0.2	
	w_rethink	0.25	
	w_standardisationinfluence	0.1	
Economical weights	w_economicalimpact	0.2	
	w_turnover	0.5	
	w_attraction	0.3	

Table 9: Weights for computing SPI

Please note that while the definition resulting in Equation 4 is subjective, the evolution of its value follows the evolution towards Green IT, as defined in Chapter 2. Moreover, it can be easily changed to reflect any other aspect not yet included.

Once computed, the percentage of change in the SPI value is diffused to the contacts of one actor, from informal contacts to direct partnerships and projects members. Each of these will update its SPI value by adding to its own value a fraction of this change (being positive or negative). This impact reflects the diffusion of sustainability within the network of contacts.

5.3. Results

5.3.1. Experimental setup

The algorithms depicted in Chapter 4 and the computation of performance indicators are implemented in NetLogo. NetLogo provides a GUI that can be totally customized so as to show the evolution of actors and selected metrics during the simulation.

While this graphical view is useful for developing the model and testing it against different conditions, it is not mandatory if one wants only to run the model for a while and retrieve metrics for statistical analysis. Therefore a direct java program can be called, and one experiment run without graphical feedback.

An experiment is described either in an XML file, or using the graphical interface. Any global value in the model and any configuration can be tested, and repeated a given number of times. For instance, it is possible to run the model with or without active TTOs, changing the funds distributed by funding agencies, or change the number of companies, research facilities, or researchers. Without updating the graphical interface and the different plots the simulation is much faster, and can even be embarrassingly parallelized, one instance running a different experiment.

For each simulation, it is possible to keep all data from all steps, or to keep only final values. We decided to use here only the final values, and only to present the evolution of the metrics on one simulation, for the sake of understanding.

All the values and graphics presented in this dissertation are mean values from 50 runs with the same parameters: Indeed, since the behaviour of the agents is stochastic, each run (with a different random seed) results in different values.

Each single run lasts about 10mn for the studied world (with 10 research facilities, 20 companies, 4 TTOs and 50 researchers), on an Intel i7 running at 2.66 GHz with 4 Go of RAM. In order to be able to get results from a large set of experiments, the cluster of the laboratory has been used. Scripts in Bash shell, Python and Gnuplot have been developed to start the experiments on the cluster, to retrieve results and to produce automatically the graphs shown in this Chapter.

5.3.2. The studied world

While it would have been interesting to investigate several parameters for all global variables, we restricted ourselves to changing only some parameters and to fix the other ones.

The number of actors in the system is an important parameter. We fixed the number of research facilities to a maximum of 10, the number of researchers to a maximum of 50, and the number of companies varies among 10, 20 or 50. The number of TTOs is set to 2, 4, 8, or 10. Please note that we also tested our model with 20 research facilities, 100 researchers, 50 companies and 10 TTOs, and the results were very similar to this case. The reasons for these values are: The number of research facilities having an activity in Green IT is limited. In these institutes, only a small group of researchers are actually working on Green IT, teams of about 5 to 10 permanent researchers in each institute is already a large number. Any research facility has at least 3 researchers. While the number of research facilities could have been set by counting the number of these research facilities working on Green IT, we think that what is more interesting is to evaluate the impact of the ratio of companies having contracts with research facilities. A ratio of 1, 2 and 5 was setup to compare situations. When the ratio is high, the number of company is therefore high and in that case the simulation of the system is very long. Also, even if the potential for companies is very large, if we restrict to the ones having a research activity linked with IT, the potential is limited. For instance, in France, on the more than 3.14 million companies, only 20000 are declaring doing research (i.e. less than 1% in 2012), and on this number, only a few are doing research in IT and for small amounts (less than 11.9 % in amount declared for IT companies, that have to be combined with amount from companies in other sectors participating in research program in IT). These numbers are taken from reports from the ministry of research, studying the impact of tax incentive for research (CIR program in France) [5.1]. The relatively small numbers can be explained by several factors, one being that big companies have their main research centres outside France, second being that small start-ups in IT have a limited budget for this (even if R&D staff represents for them more than 40% of the staff). From this, it is very difficult to know which percentage participate in research in Green IT. For the TTOs, we wanted to study the impact of having a TTO for a research facility.

At the beginning of the simulation, the informal network between actors in set to be scale free. While we also implemented (during the bachelor internship of V. Deniau) other network structure (random and small world), we kept only this one: Indeed, after few simulation steps, new contacts are established by the model evolution, and the properties of any network structure is not guaranteed (we could have directed the contact so as to keep these structures, which was not done). Also, simulations using different original networks structure did not give significant differences on the studied parameters.

The parameters of one simulation are given in Table 10 (besides weights of SPI, already discussed):

number of research facilities		10-20
number of researchers		50-100
number of companies		10 – 20 - 50
number of ttos		2 – 4 – 8 – 10
conversion	contract to patent conversion rate (percentage) for a company	10%-20%-30%-50%-70%-80%-90%
incentive	percentage of turnover a research facility has that will return to the research	10%-20%-30%-50%-70%-80%-90%
percentage	percentage a TTO takes on every contract	20%
tto_to_RF_back_percentage	percentage a TTO gives back to its research facility	10%-20%-30%-50%-70%-80%-90%
max_link_per_researcher	maximum number of neighbours a researcher could get in contact	10
RF_history_size	research facility history size to compute reputation	365 * 3
cost_per_day	cost of one staff per day, average	50000 / 365
funding_agencies	rhythm funding agencies will provide fund to projects	365 / 2
min_funding	minimum funding for one project	1000000
max_funding	maximum funding for one project = min_funding + max_funding	1000000-2500000-5000000-7500000
min_turnover	minimum turnover of a company	100000
min_contract_amount	minimum contract amount	100000
max_initial_turnover	maximum initial turnover of a company	5000000

Table 10: Parameters of the simulation

5.3.3. Graphical view: Evolution of multi-agent-system during one simulation

While many graphs can be produced by the GUI, it would not be interesting to display and explain all of them here, especially because the more detailed analysis will be conducted on statistical analysis of a set of experiments, as explained earlier. We selected therefore a limited number of values to exhibit their evolution during one single run.

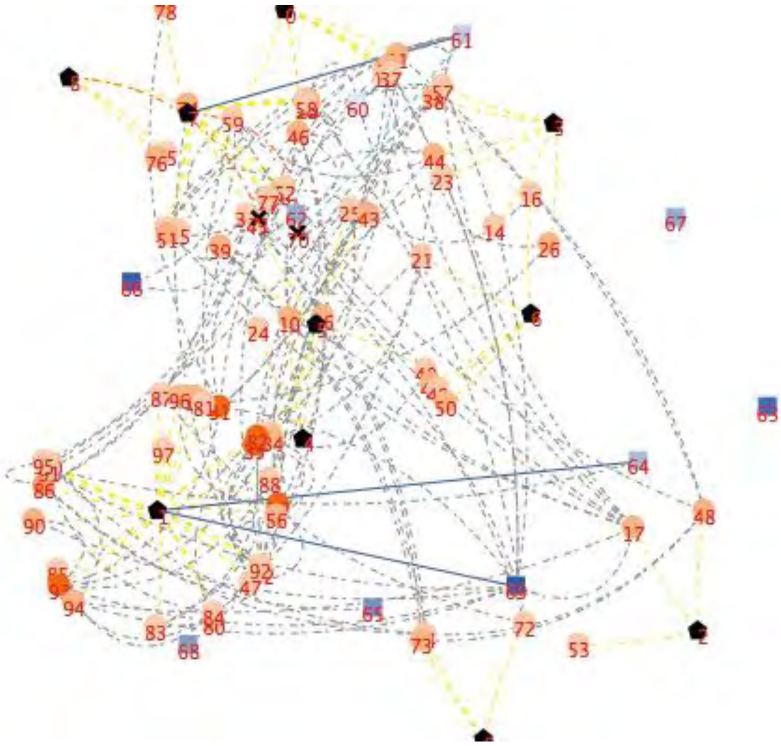


Figure 6: Studied world

Figure 6 displays the graphical view of the world. Circles are researchers (75), pentagons are research facilities (10), square are companies (10) and crosses are TTOs (2). Yellow dashed lines represent the link one researcher has with its research facility, while dashed grey lines represents regular links between researchers and companies. Solid blue lines represent partnerships while red lines represent project links (not present here). This snapshot has been produced after only 300 days, and the number of links is still limited. During that period some partnerships have been started, new employees hired (25 non-permanent staff in research facilities), some links have appeared or died. We can easily imagine that with a larger world and a longer simulation time, this view becomes non-practical.

Figure 7 exhibits the evolution of the reputation of the research facilities. Since the reputation is computed on the performance of the last 3 years, its evolution has high and downs during the simulation. The 3 curves represent the minimum, mean and maximum values. The same applies for the mean richness of the companies (Figure 8), where the richness is defined as the combined sum of its turnover and its funding for research. It decreases when a company invests in research, and increases when the partnership or the project ends and is being successful.

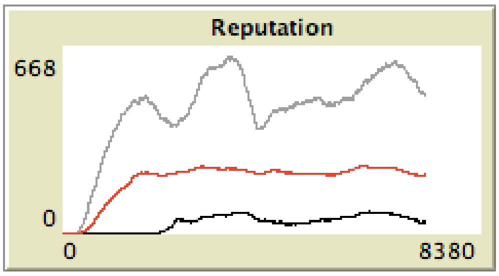


Figure 7: Evolution of the mean reputation of research facilities

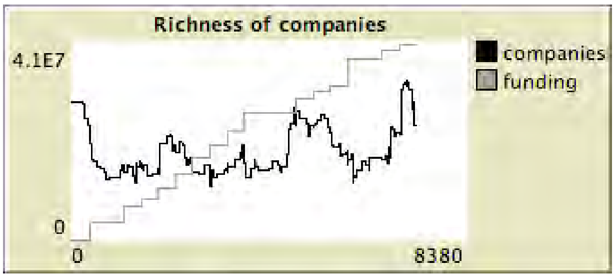


Figure 8: Evolution of the richness of the companies

Finally, shows the evolution of two elements of the SPI, namely the image and the rethink parameters during one simulation.

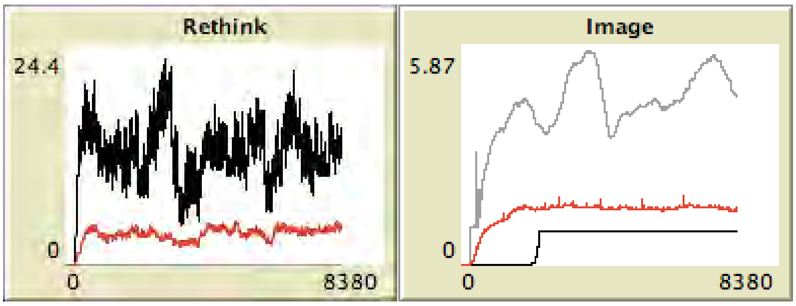


Figure 9: Evolution of parameters of the SPI

When analysing one single simulation, several elements can been outlined: First, the difference between maximum and minimum values can be high on some parameters, confirmed by a proper analysis of their variance. This implies that a minimum number of runs must be executed to validate a sound analysis. We set this number to 50.

The second observation that can be drawn is that the end date of the simulation has an influence on the final values. The multi-agent system can easily be configured to stop after 10 years for instance (3650 runs) instead of the 20 years used in this section for analysis (7280 runs). Indeed, while the interest of some funding agencies could be seen on the very long term, a company might want to see the evolution only for the next 5 to 10 years instead.

The last observation is that it is necessary to select the parameters to study and to compare between the experiments.

5.3.4. Selected variables

The studied parameters we selected are the ones related to the respective objectives of the actors of the multi-agent-system, so as to understand how they manage to get closer to their objectives:

- The mean number of publications of the permanent researchers
- The sum of the research output of the research facilities
- The mean reputation of the research facilities
- Tthe sum of the richness of the companies
- Tthe mean turnover of the TTOs
- One other variable is studied: The mean SPI of the research facilities and the companies.

5.3.5. Impact of presence of TTOs as a function of the number of companies

The first experiment was set to study the impact of the number of companies in the multi-agent-system, taking 10, 20 and 50 companies, and with the number of TTOs, taking 0, 2, 4, 8 and 10 TTOs. The number of research facility is set to 10.

The other parameters are:

funding	2500000
incentive	30%
tto_to_RF_back_percentage	30%
conversion	30%

Figure 10 show the mean number of publications for permanent researchers. The x-axis represents the number of TTOs, and for each number of TTO, 3 cases are represented (10, 20 and 50 companies, from left to right).

The first observation is that for each case, the number of publication increases with the number of companies. Indeed, more companies allow each researcher to connect more, and since publications are a function of the number of contacts, the number of publication increases, up to about 6%.

The second observation is that for the cases with 10 or 20 companies, the number of TTOs does not seem to have an impact, and for the case of 50 companies, the number of TTOs seems to have a (limited to 3%) negative impact on the mean publication or permanent researchers.

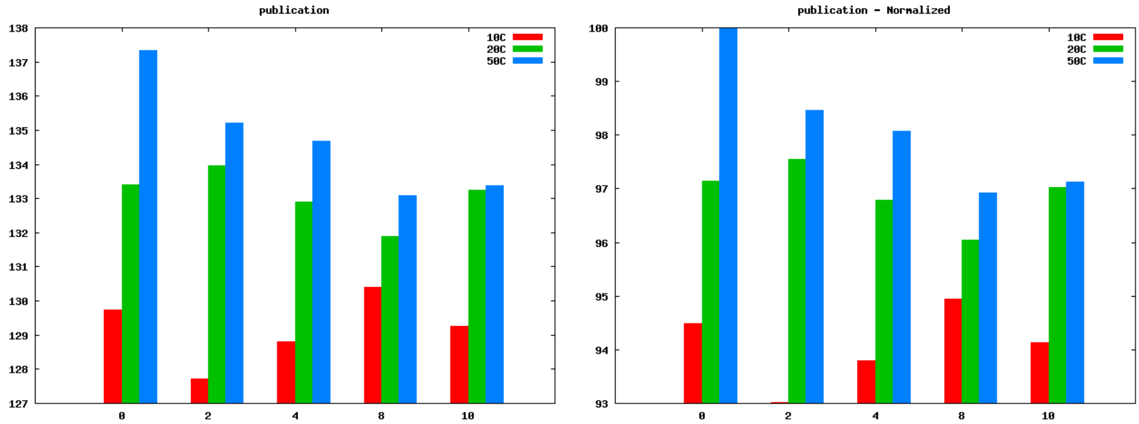


Figure 10: Impact of number of companies and number of TTOs on mean publication of permanent researchers (left: raw values, right: normalized)

The same observations can be seen from the research output (Figure 11) and reputation (Figure 12) point of views. Since research output and reputation also account for the activities of non-permanent researchers (their publications are counted), the difference between the 10 companies case and the 50 companies case reaches more than 35% for the research output and 32% for the reputation.

From the research output point of view, the difference between the cases with different number of TTOs is limited to less than 6% for 10 companies and 17% for 50 companies. From the reputation point of view, the difference between the cases with different number of TTOs is limited to less than 5% for 10 companies and 12% for 50 companies.

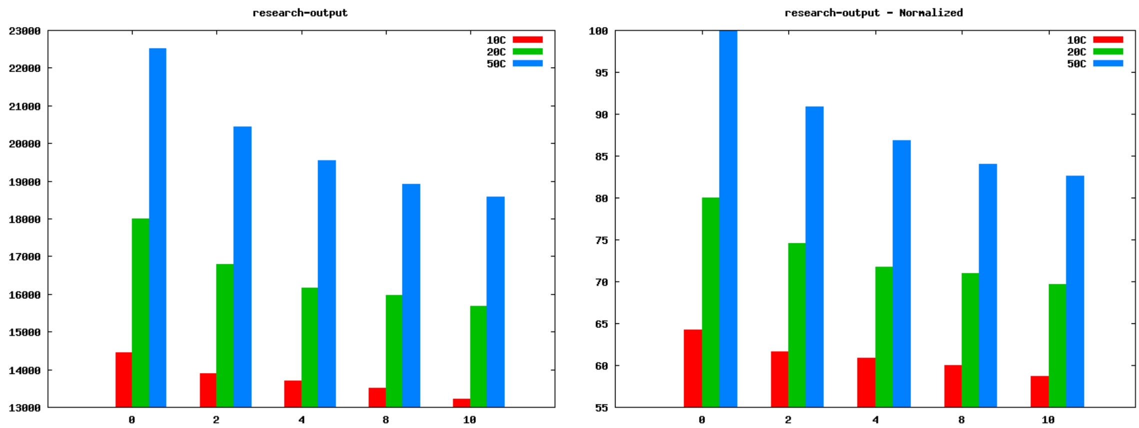


Figure 11: Research Output of research facilities (left: raw values, right: normalized)

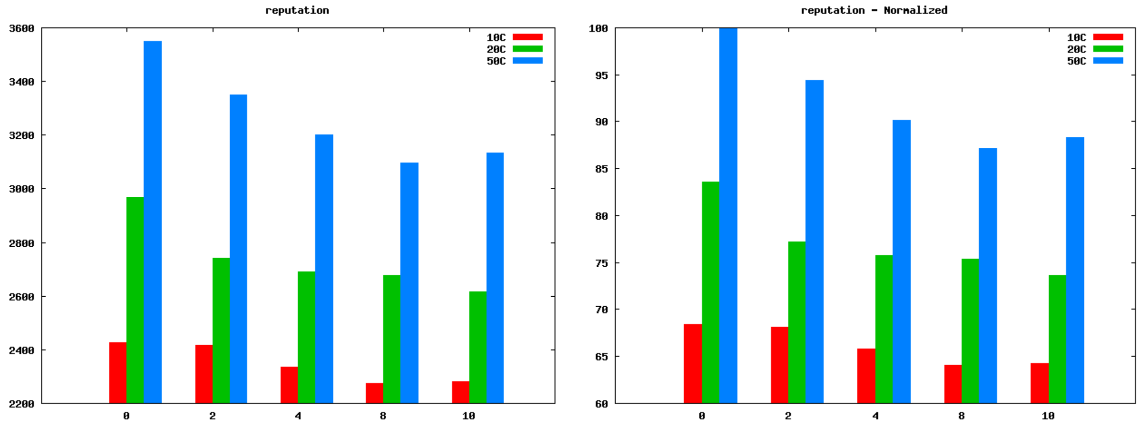


Figure 12: Reputation of research facilities (left: raw values, right: normalized)

In all cases, it seems that the presence of TTOs is degrading the performance of the research facilities. We decided therefore to investigate the research output and the reputation of the research facilities without TTOs and to compare these performances with research facilities with TTOs. The results can be found in Figure 13. These graphs confirm that the presence of TTOs does not help the research facilities to improve its reputation and its research output.

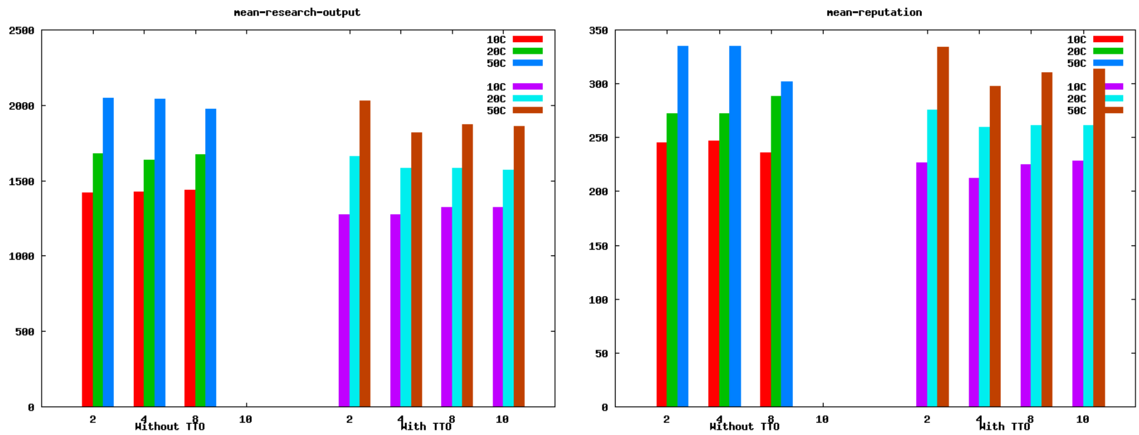


Figure 13: Mean research output (left) and reputation (right) of research facilities without TTOs (left on the graphs) and with TTO (right on th graphs), for different number of companies and TTOs

The richness of the companies can be observed on Figure 14. It shows that the richness is not much related to the number of TTOs, for the cases with 10 and 20 companies. The best case is with 50 companies where the companies' richness is higher with 8 TTOs with an improvement of less than 10% compared to other cases (0, 2, 4, and 10 TTOs).

An interesting observation is that while the number of companies is multiplied by 2 and 5 compared to the first case, the total richness is multiplied by more than these factors. An explanation can be that with more companies in the system, more partnerships and projects are setup leading to a nonlinear increase of the richness of the system.

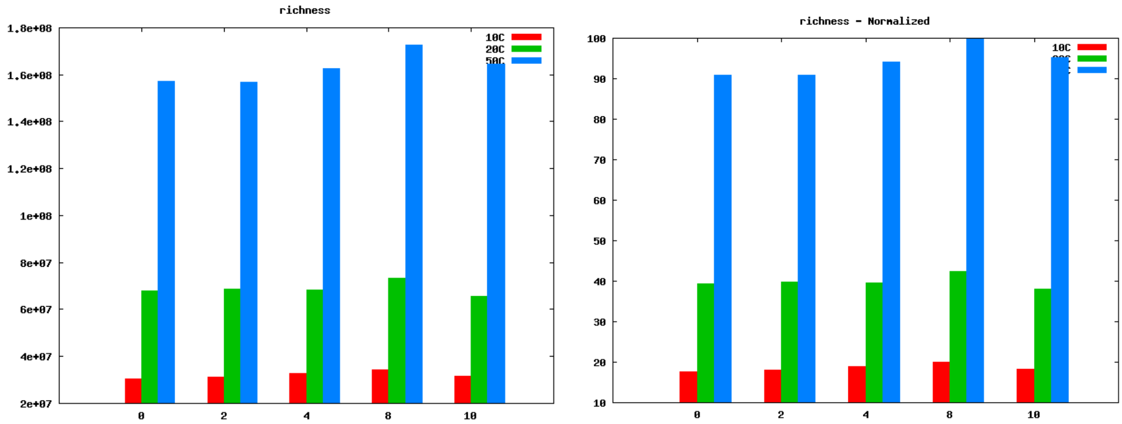


Figure 14: Richness of companies (left: raw values, right: normalized), for different number of companies and TTOs

The mean SPI indicator is displayed in Figure 15 for the different cases. What can be observed is that it decreases with the number of companies. More companies mean less contracts in average for these companies, meaning also less newly employed staff. While the calculation of the SPI indicator is taking this into account, each company will have a lower indicator, leading to an overall lower mean value. Comparing the cases of the different number of TTOs does not lead to a clear conclusion, meaning that it does not have a large impact on the SPI indicator.

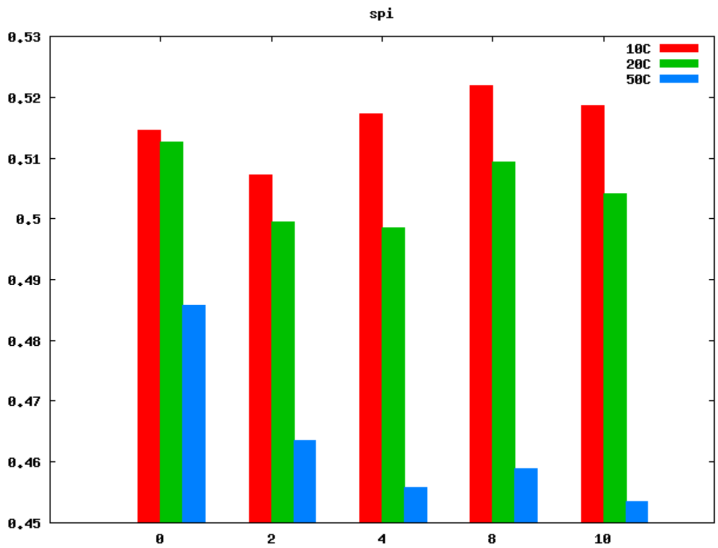


Figure 15: Impact of the number of TTOs on SPI indicator, for different number of companies

5.3.6. Impact of funding

In this section, we study the impact of the funding given for the projects by the funding agencies. The higher the maximum funding, the more projects could be funded, if enough partners are available to start a project (see algorithm 5).

Remember that this only impacts projects but not direct partnerships between one company and one research facility.

The parameters are:

nb companies	20
nb ttos	4
incentive	30%
tto_to_RF_back_percentage	30%
conversion	30%

Remember that the total funding distributed to each call is `10*max_funding+random min_funding`, and each project gets `min_funding + random max_funding`. Increasing max_funding increases the total amount distributed to projects, and the size of the projects in terms of amount. Also, a call is issued every 180 days.

In Figure 16 the impact of funding on the companies' richness is exhibited. Altogether, we can see that the impact is positive when `max_funding` is raised from 1M€ to 2.5M€, but afterwards, the impact is not anymore positive, even a bit negative. In the system, the number of companies is limited and each company has a random number of internal human resources, set at the beginning of the simulation. Since each project and partnership needs at least one staff member, the number of potential collaboration is limited. Even with more funding, no more projects are started. It even decreases for companies probably because when the size of the project increases, the share of each partner increases, which means, for a company, that the initial investment increases. Since all project are not successfully converted (conversion=30%), this turns out for the company to lose more, reducing therefore its richness.

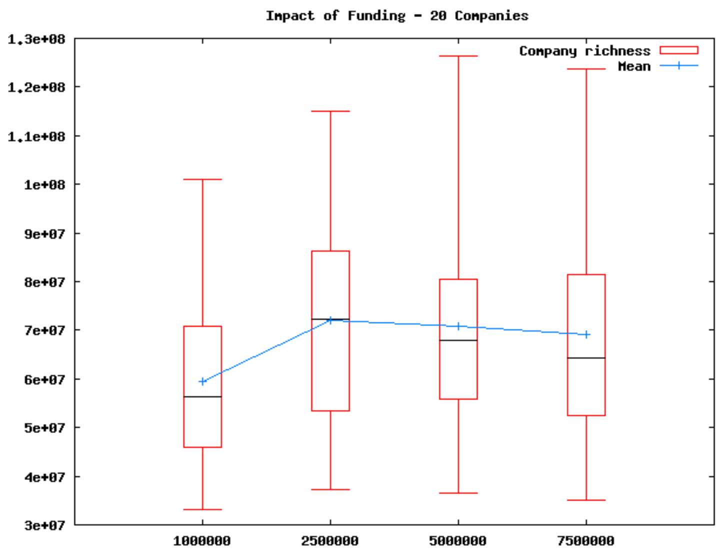


Figure 16: Impact of funding on companies' richness

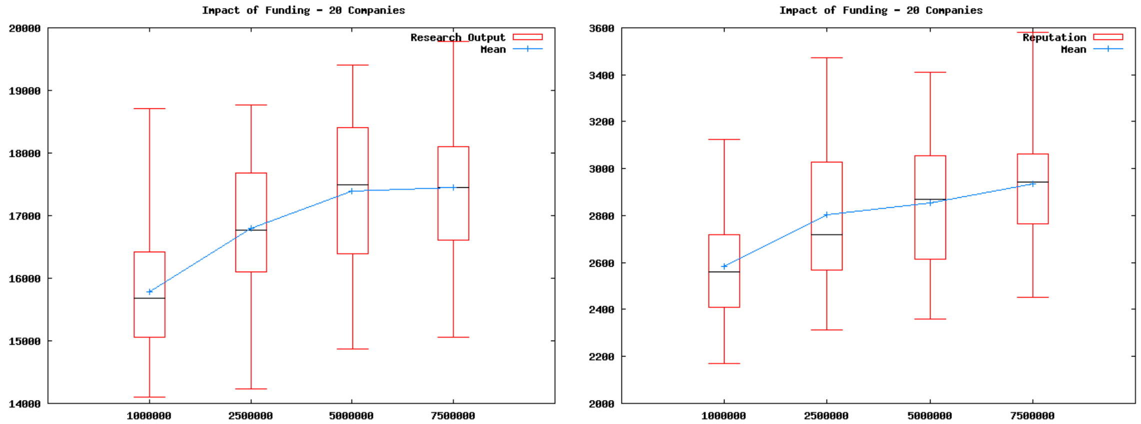


Figure 17: Impact of funding on research output (left) and reputation (right) of research facilities

Figure 17 exhibits the raise of research output and reputation of the research facilities. These actors benefit directly from the raise in funding from these perspectives. With more money in projects, it is likely that each research facility can hire more non-permanent researchers and finally produce more research and increase the reputation of the research facility.

In Figure 18 we studied the impact of having a TTO or not for a research facility, in terms of research output and reputation. For both cases, the research facilities perform better without TTOs than with TTOs, even if the differences are rather small.

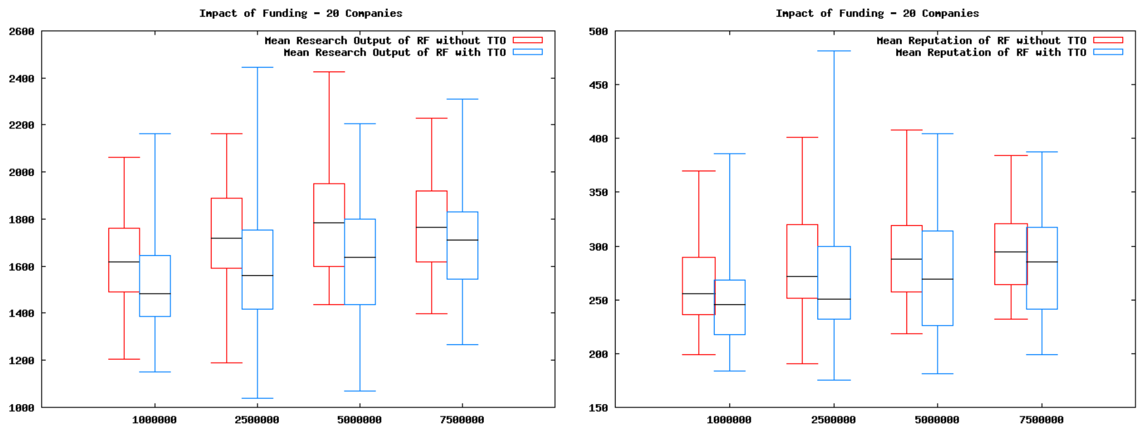


Figure 18: Impact of funding on mean research output (left) and reputation (right), without TTO (left in each graph) and with TTO (right in each graph)

From the permanent researchers' point of view, the funding has little impact, as shown in Figure 19. This can be explained since the researcher publication rate is influenced mainly by the size of its network, which is increasing close to its maximum size (set to 10 in the experiments) and few by the research facility funding.

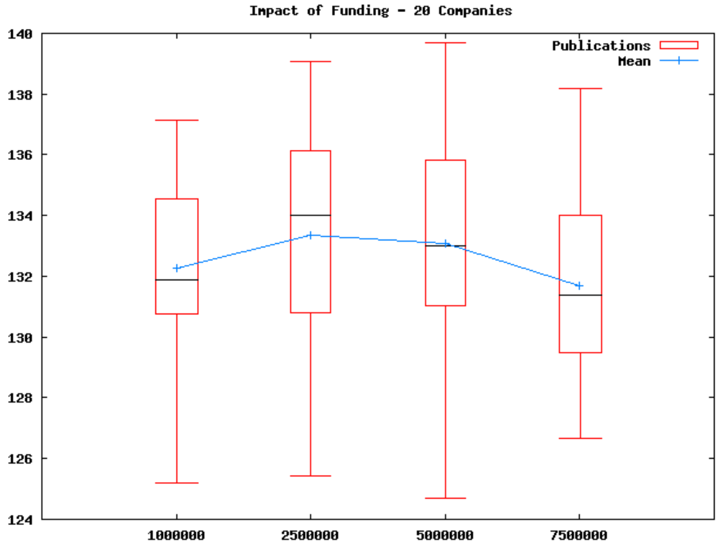


Figure 19: Impact of funding on mean publications of permanent researchers

Figure 20 displays the effect of the funding on the TTOs turnover. Since a TTO is funded by the percentage it takes on every project and transaction (fixed to 20%), its turnover is not surprisingly increasing with the amount distributed.

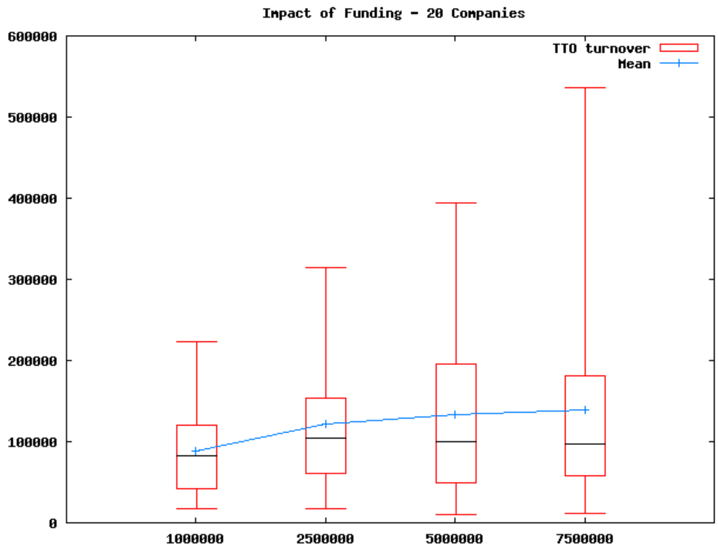


Figure 20: Impact of funding on the TTOs' turnover

Finally, shows the impact of funding on the SPI indicator. The impact is quite limited, with a small increase, due to the higher number of researchers in research facilities. Actually, the SPI calculation depends on the number of researchers, either directly (greenemployment) or indirectly (more employees means higher standardization influence, more publications, etc.).

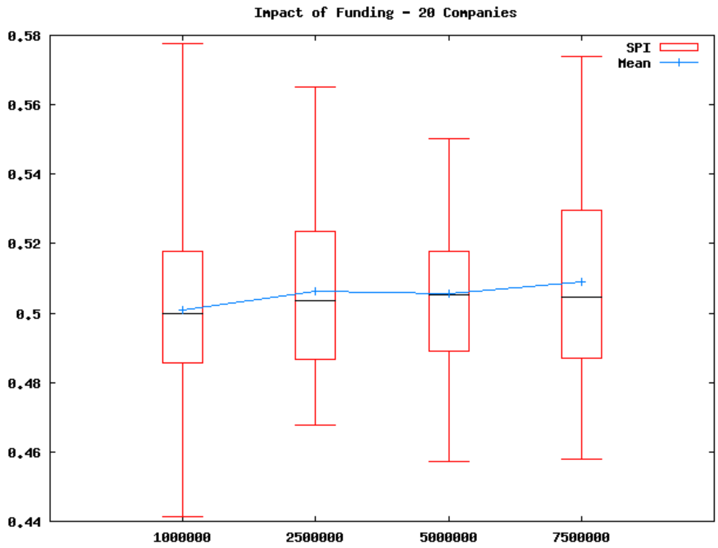


Figure 21: Impact of funding on SPI indicator

5.3.7. Impact of conversion rate

In this section, we study the impact of the conversion rate at the end of a partnership or project. The higher it is, and the more outcomes are generated in terms of benefits for the partners.

The parameters are:

nb companies	20
nb ttos	4
incentive	30%
tto_to_RF_back_percentage	30%
max_funding	2500000

Figure 22 shows that the higher the conversion rate, the higher the richness of the company is. This is not surprising since a high conversion rate such as 90% for instance means that almost all projects generate profit. Also these profits are redistributed among partners of the partnership or project, hence the turnover of the research facilities and their TTOs are also increased.

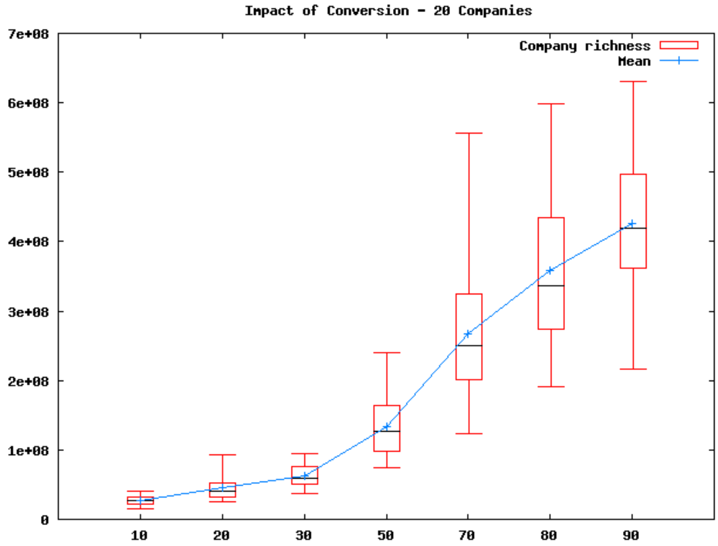


Figure 22: Conversion rate impact on companies' richness

This extra money in companies allows for more new partnerships and projects for companies, and in research facility, more researchers are hired, more contracts are signed, leading to an increased reputation and research output (Figure 23).

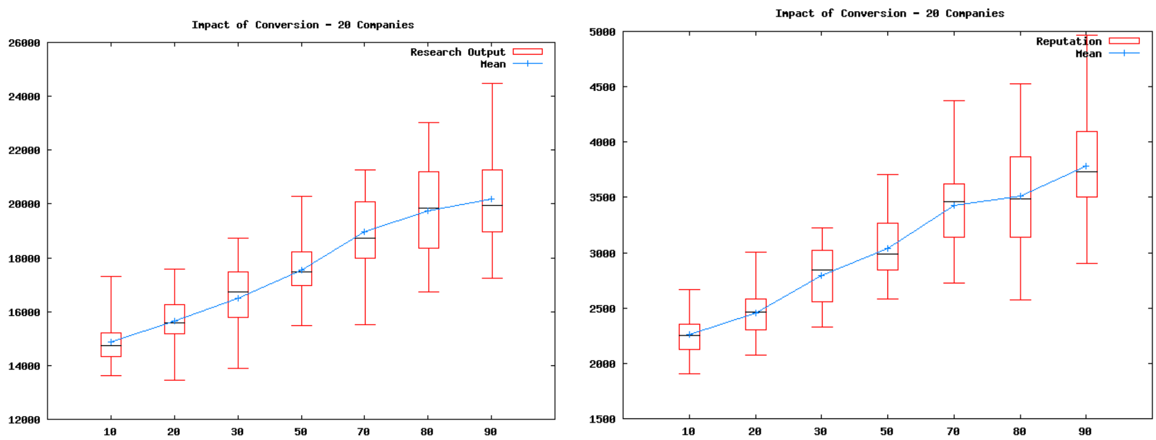


Figure 23: Impact of conversion rate on research output (left) and reputation (right)

In Figure 24, the mean research output of research facilities without (left) and with (right) TTOs, together with the same for reputation are displayed. For both cases, the means are increasing with the conversion ratio, but the difference between without or with TTOs is small, with a small advantage for research facilities without TTOs.

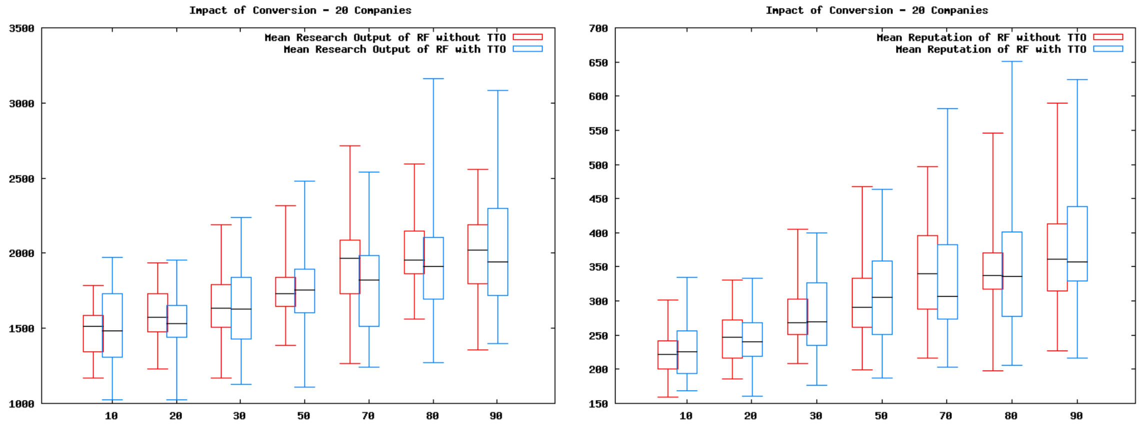


Figure 24: Impact of conversion rate on means of research facilities' research output (left) and reputation (right), without and with TTOs (left and right on each graph, respectively)

Interestingly, in terms of the permanent researchers, the number of publications remains stable, whatever the conversion rate (see Figure 25). Combining this observation with the ones on the research facilities metrics above, we conclude that the main differences are observed thanks to the employment of non-permanent researchers.

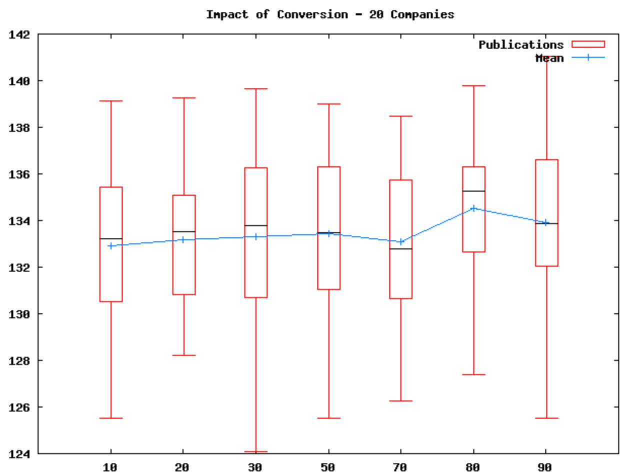


Figure 25: Impact of conversion rate on the mean number of publications of permanent researchers

Finally, Figure 26 shows the impact of the conversion rate on the SPI indicator. Its value increases with the conversion rate. It can be explained by the high new employment raised by larger conversion rate, that impacts several parameters in the SPI calculation, either directly (greenemployment) or indirectly (more employees means higher standardization influence, more contracts, more publications, etc.).

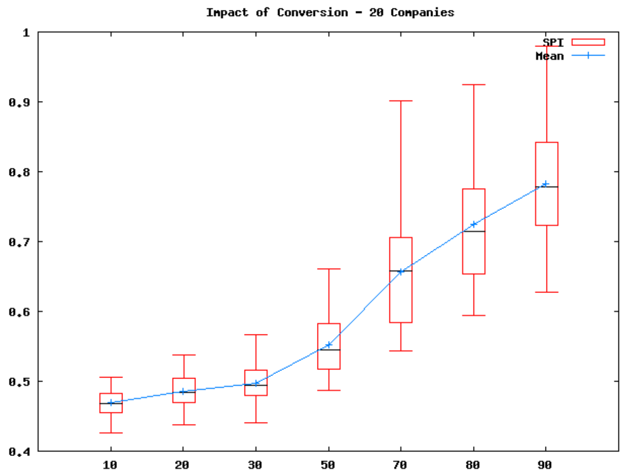


Figure 26: Impact of conversion rate on SPI indicator

5.3.8. Impact of incentive

In this section, we study the impact of the incentive rate that a research facility is dedicating to research, i.e. the percentage of turnover that returns to funding research. The higher it is, and the more money goes to funding research in research facilities. A research facility is doing transferring money every 120 to 240 days (in average 6 months, each research facility has a different action period).

The parameters are:

nb companies	20
nb ttos	4
conversion	30%
tto_to_RF_back_percentage	30%
max_funding	2500000

Figure 27 displays the mean number of publications as a function of the incentive percentage. Its value increases with the incentive, meaning that permanent researchers publish more when the research funding is higher.

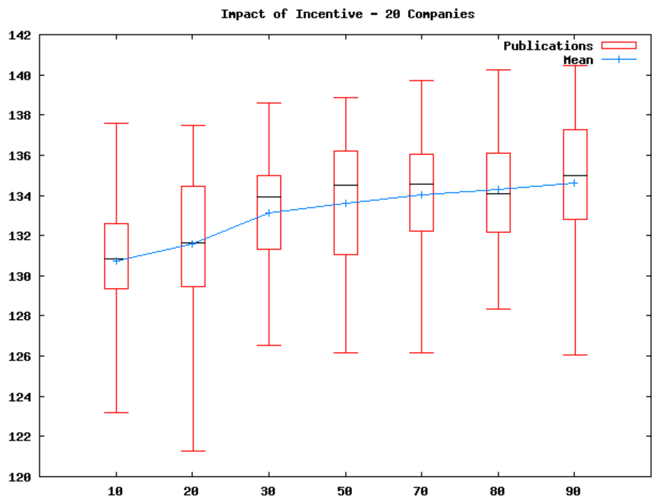


Figure 27: Impact of incentive on mean publications of permanent researchers

On Figure 28 one can see that however its impact on the research output and the reputation of the research facility is very small, with even a small tendency to decrease as the incentive grows. The research output is computed as the sum of all publications of all the research facilities. With 50 permanent researchers, the amount of publications related to these researchers is equal from about 130*50=6500 to 135*50=6750 (see Figure 27), while the total research output is about 16000. This explains the stability of the research output and reputation. Moreover, when more money is transferred to funding research, the research facility has less possibility to hire more researchers (the turnover is taken into account to hire new staff), and even leading ultimately to fire the non-permanent researchers. This leads to possibly less contracts and less publications from non-permanent researchers, decreasing the research output and reputation slowly.

The same graphs are valid for research facility with and without TTOs (the split is not shown here).

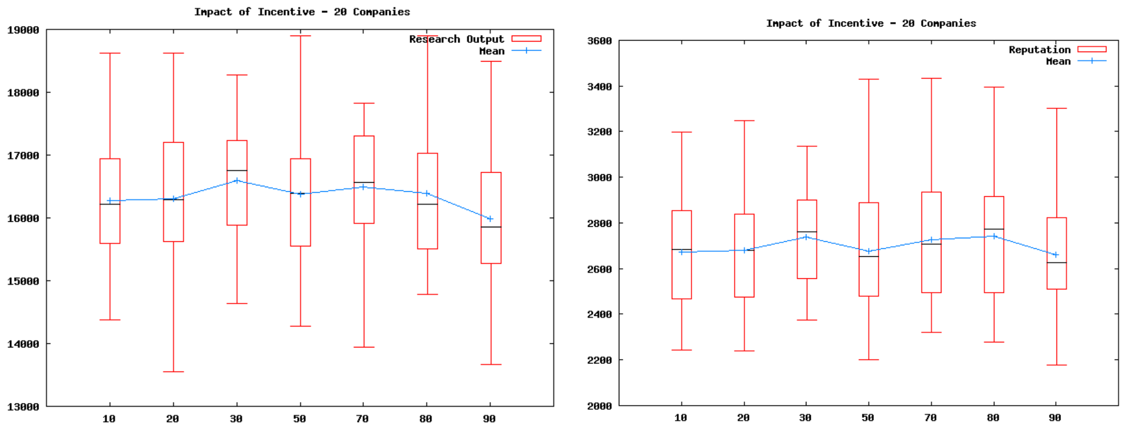


Figure 28: Impact of incentive on research output and reputation of research facilities

The impact on the companies' richness and the TTOs' turnover are not significant and are not shown here. Actually the company richness is loosely related to the behaviour of the research facilities since only free permanent staffs in research facilities are taken into account to start projects and partnerships. The same argument is valid for TTOs' turnover that increases with projects and partnerships.

The Figure 29 shows the value of the SPI indicator with different values of incentive. We can see a slow decrease of the SPI with an increase in the incentive after 30%, probably due to a smaller new employment number in research facility, as explained above.

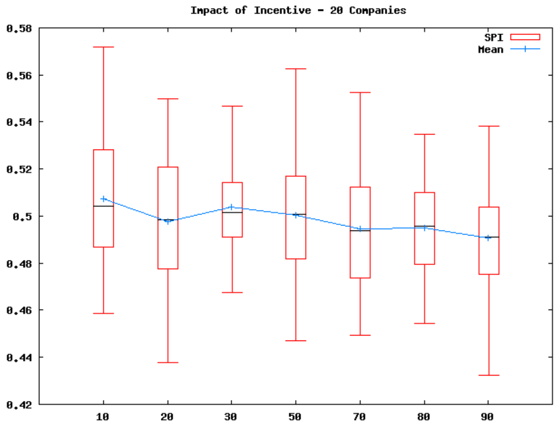


Figure 29: Impact of incentive on mean SPI

More studies could be done concerning the impact of incentive, in particular by changing the action period of the research facilities (for instance so that they fund research every month instead of every 6 months in average), and to analyse more closely its impact on each parameter of the SPI.

5.3.9. Impact of the percentage of TTOs redistribution

In this section, we study the impact of the percentage a TTO returns to a research facility. The higher this percentage, the higher money returns to the research facility, and the more funding a research facility has. A TTO is distributing the money on a regular basis, different for each TTO, and set between 30 and 90 days.

The parameters are:

nb companies	20
nb ttos	4
incentive	30%
conversion	30%
max_funding	2500000

The impact is seen on the TTO's turnover that decreases with the percentage, not surprisingly. Since more money is returned to the research facility with an increased percentage, the amount that stays in the TTO is lowered.

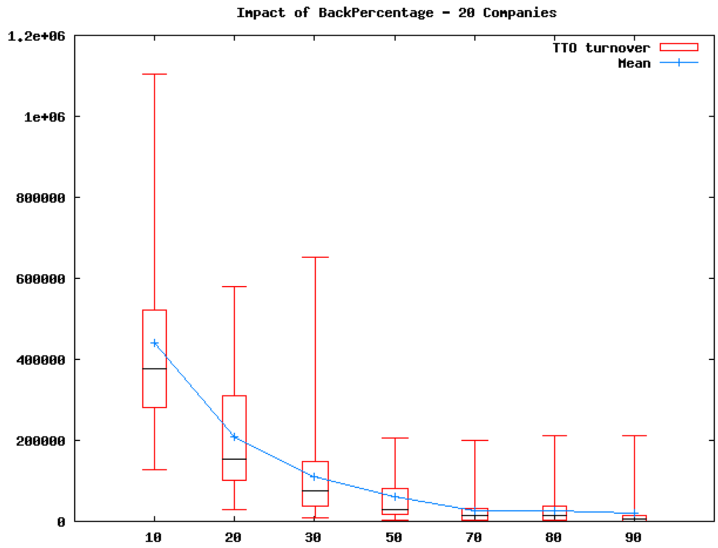


Figure 30: Impact of back percentage on TTOs' turnover

Interestingly, the impact on the other actors is not visible, all graphs being stable whatever the value of this back percentage. The reason is probably because since the share a TTO is taking from a project is low (20%), the main amount of the money goes to the research facility already, and this back distribution is not giving extra possibilities for research facilities that have already enough money (which can be actually witnessed in the experiments), leading to no more incentive to the researchers and for creating new collaborations.

An interesting study could be to investigate the impact of the initial percentage a TTO is taking from a project (beyond the current 20%).

5.4. Integrating SPI in the model

So far, only an observation of the value and the evolution of the SPI indicator has been proposed. To go a bit further, I adapted the model so that actors are actually changing their behaviour as a function of the SPI values.

This section details the changes made to the model and the results obtained with these changes, comparing the cases with and without having a behaviour related to SPI.

5.4.1. Modelling using SPI

To be able to understand the changes in results due to the changes in the model, only the following updates have been done in the model:

- For a researcher: When a researcher creates a new contact, it searches among all potential contacts based on the SPI values, instead of his compatibility with others. Therefore other researchers and companies with higher values of SPI will be favoured in this choice.
- For a research facility: When it creates a new project, it will favour the choice of partners with higher values of SPI.
- For a company: When it creates a new partnership, it will favour the choice of partners with higher values of SPI. Also, a company will invest in research as a function of its relative (compared to other companies) SPI. If it has a small relative value of SPI, it will put more money for research and ultimately create more partnerships and projects.

- For a TTO: When it is asked for a potential partner by researchers or research facilities, it will favour the ones with a higher value of SPI.

At this point we could show the different graphs obtained, such as in Section 5.3. We preferred to focus on a smaller set of experiment, and to fix a number of parameters, and to show only normalized graphs comparing the cases with and without the behaviour following SPI (noted as Without_SPI and With_SPI in the following graphs).

5.4.2. Impact of funding

In this section, we study the impact of the funding given for the projects by the funding agencies, with and without SPI. The parameters are the same as is Section 5.3.

The first observation on Figure 31 is that the situation without SPI is better than the situation with SPI behaviour for the companies richness (left) and the mean TTOs turnover (right), when the funding is higher than 1M€ (up to 14% difference for 2.5M€). The other observation is that the companies' richness is more stable whatever the funding. This means that introducing SPI in their behaviour does have a negative impact on the global richness but that the companies are less sensitive to outside funding.

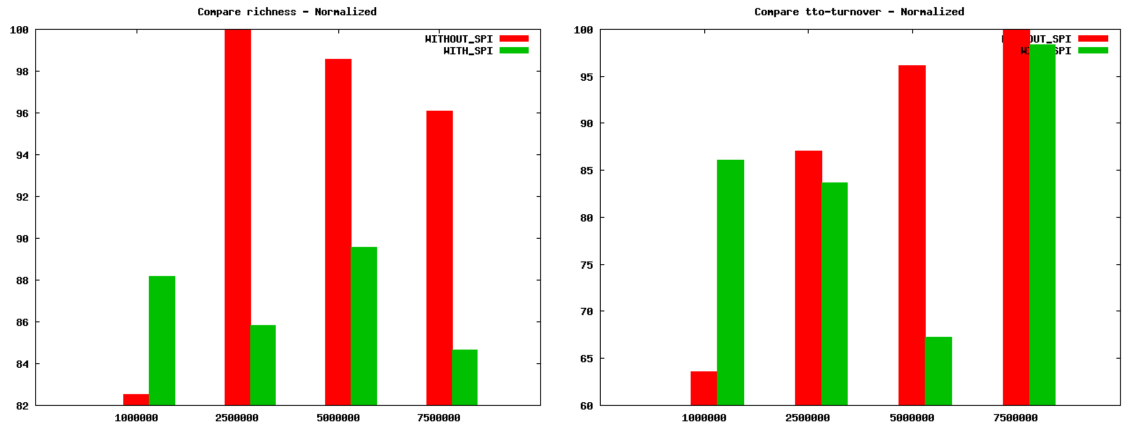


Figure 31: Impact of funding with and without SPI: left: companies' richness, right: mean TTOs turnover

Graph on Figure 32 shows that for publication (up), research output (down left) and reputation (down right), integrating SPI was not beneficial. However, the percentage of loss are quite small, with less than 8% for publications, 5% for research output and 6% for reputation.

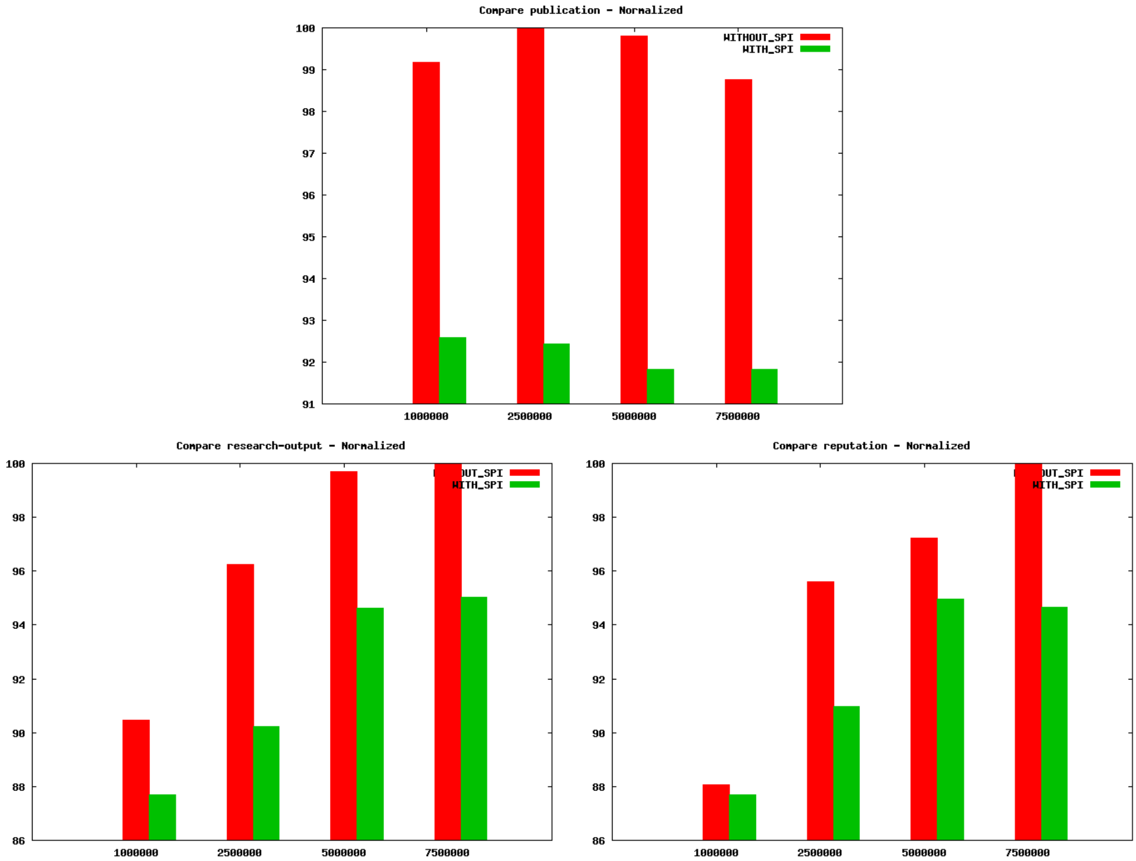


Figure 32: Impact of funding on publication, research output and reputation, with and without SPI

Finally, Figure 33 exhibits the results for the SPI indicator. Since the value shown is the average of all companies and research facilities, its value is decreased when using SPI compared to before. However the percentage of difference is very low (less than 2%). It is likely that the actors with a low level of SPI at the beginning of the simulation keep low values, degrading this averaged value. With a more random behaviour (i.e. without SPI), the SPI is altogether increased more uniformly among actors. However this hypothesis would have to be confirmed by further experiments.

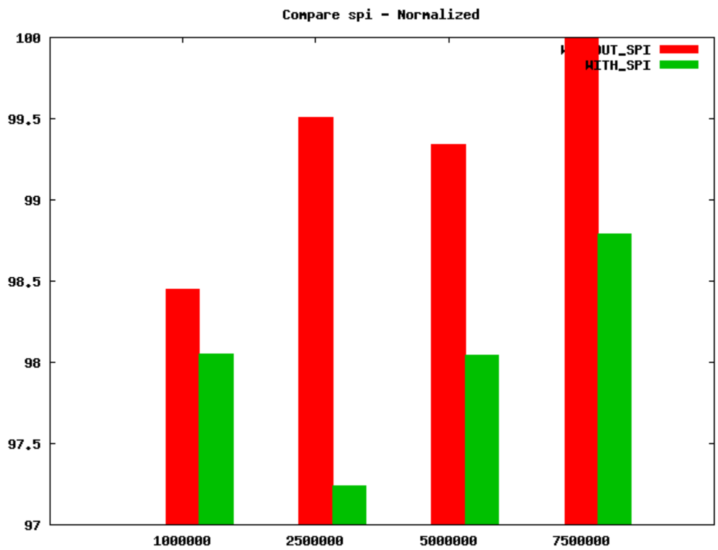
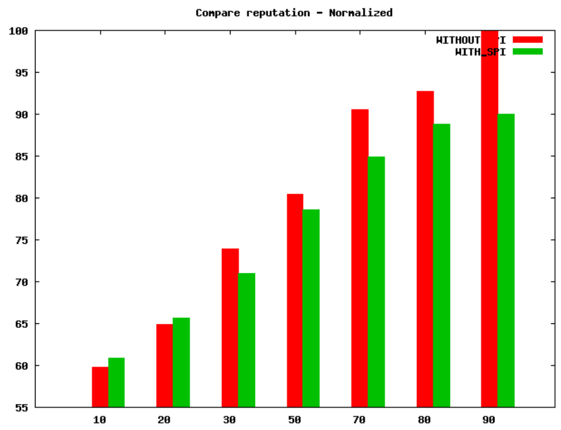


Figure 33: Impact of funding on SPI, with and without SPI behaviour

5.4.3. Impact of conversion, incentive, percentage of TTOs redistribution

We conducted the same experiments than the ones presented in Section 3, varying conversion rate, incentive and percentage of TTOs redistribution.

In almost all these experiments, the case without SPI is better than the case with SPI. When it is not the case (for instance for the reputation, in an experiment varying the conversion rate, see Figure 34-left, or for the reputation, in an experiment varying the incentive, see Figure 34-right) is it only by few percent.



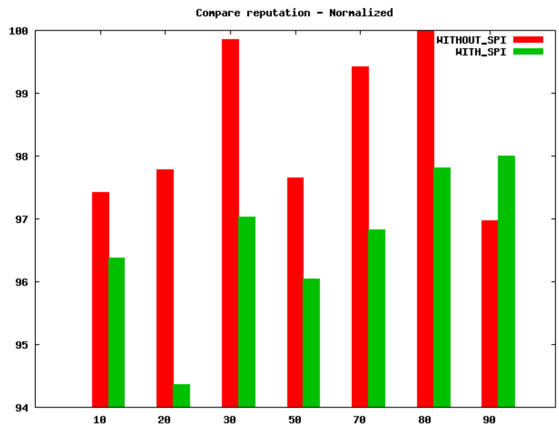


Figure 34: Reputation with and without SPI behaviour. Left: impact of conversion ; Right: impact of incentive

From these experiments, we conclude that our agents are not changing their behaviour enough towards better values of SPI. More investigations will have to be conducted in order to select the key behaviours that can lead to better values of SPI.

5.5. Discussion on the experiments

In this chapter, we conducted a set of experiment, with 4000 runs that lead to the presented graphs (not counting the different experiments necessary to debug the model). From the 2000 runs those results are presented in Section 5.3, still some studies must be conducted to better understand the impact of each parameter. Also a number of parameters have not been studied and fixed for all simulations (for instance the number of research facilities, the number of researchers, the number of links one researcher can have, …). Their impact must also be investigated.

From the 2000 runs conducted with the SPI behaviour of the actors the main conclusion that can be drawn is that this behaviour is not improving the model for the key indicators at hand. The reasons for this can be manifold: One is related to the calculation of the SPI indicator itself, the other one being the integration of SPI behaviour in the model.

The final objective is still to provide a tool helping to decide the impact of some decisions on each actor. Thanks to the developed model and validated by experiments:

- Each actor can study the impact of decisions on its Sustainability Performance Indicator
- A funding agency can study the impact of the proposed funding and the rate of funding;
- A research facility can study the impact of giving back some incentives to the researchers;
- A researcher can study the impact of favouring some links compared to others (for this aspect, some little coding would have to be done);
- A company can study the impact of the success of a project on its own turnover;
- A TTO can study the impact of its percentage taken from project and the one it returns to research facility.

This research prepares the next analysis and explorations:

- A thorough study on the SPI, in order to validate its calculation. This will need some interdisciplinary work with social and ecological sciences. In particular the study so far has been limited to the parameters and their weights given in Table 9: Weights for computing SPI. Other parameters and values could be investigated.
- A validation with a larger set of actors, i.e. using as a basis the survey and extend it in size in order to be able to confront the model with a larger set of real actors.
- A study on other possible adaptation of the actors to their environment, in particular to the SPI values. The preliminary work presented in this chapter must clearly be extended.

Chapter 6. Summary and Outlook

6.1. Conclusions

While state of the art researches are done in research facilities, not all of it is actually transferred to industry. This thesis investigated the links between the different actors of innovation so as to build a first analysis on their complex interplay. Also, the objective of the work was to help decision makers on the concrete aspects that have an influence of the technological transfer. In a world in which companies have to face a global market, research moves on quickly and technology evolves within seconds, knowledge transfer has to be quick, without losing information and effective. With this work we wanted to show a new approach in technology transfer in modelling the complex system. Already in other research fields like social science interactions of actors are shown.

I focused my work on a specific field, namely Green IT. However the methodology developed can be transferred to other field as well. The reasons for addressing Green IT in particular are manifold:

- The importance of this field for future developments of large scale infrastructures like Cloud
- The fact that Green IT encompasses not only technological aspects but wider societal, environmental and economic aspects, towards sustainability.
- The somehow novelty of this field making it easier to investigate the technological transfer.
- The expertise in this field in my social network, making possible a deeper knowledge and access to actual researchers, research facilities and companies in this field.

In the first part of this document, I started examining Green IT and the different reasons for its usage and we gave our final definition of it for this work. A survey was sent at the beginning of this study to over 200 people working in industries and research facilities and in the field of Green IT. The given answers showed topics influencing the development in Green IT as well as the important aspects for a long-term cooperation and it helped determine the important actors and their objectives. Building on this, we investigated technology transfer and the different possibilities of cooperation between research facilities and industries. We had a closer look on their objectives and discovered and stated their different interests.

During the last years more actors appeared in the field of science and projects. We had a look on various actors influencing projects and therefore having an influence on the progress of Green IT, hence on the society. Finally, I made propositions for an easy transfer of knowledge in Green IT, for a better exchange and understanding between industries and research facilities and possibilities to advance in Green IT.

The next step was to investigate on the links between the important actors, hence research facilities, T industries, funding agencies and standardization bodies and their influence on Green IT. We defined the links, gave examples, stated the leverages of these links towards Green IT and gave final statements if these links boost Green IT or not.

Based on these results we formalized the links and the evolution of the actors using a multi-agent system (MAS). Multi-agent systems are a key technology to help modelling complex systems where different actors (or agents) interact with each other, but where each is pursuing its own individual goal. The evolution of actors is modelled regardless of the application field first, so as to provide an agnostic reusable tool. In this model, researchers, research facilities, companies, funding agencies and TTOs are modelled. Agents interact through direct collaborations (one company and one research facility) and funded projects (more than 3 partners). The multi-agent system is developed in NetLogo and consists of about 2000 lines of code. Using Netlogo allowed us to be focused on the actors, their links, their development, and not on programming issues.

Since the developed model is independent of the targeted field, I proposed and developed a metric for assessing the evolution of the actors in terms of sustainability, based on their behaviour during the lifetime of the system. This metric is named Sustainability Performance Indicator (SPI) and allows reflecting the efforts of the agents towards sustainability, taking into account ecological, societal and economic aspects. This metric can be extended easily to reflect other aspects not yet included.

Finally, experiments are conducted to understand several parameters on the evolution of the MAS. The impact of the presence of TTO attached to research facilities, the funding given by funding agencies, the conversion rate of projects to patent, the incentive the research facilities give to their researchers and the percentage redistributed by TTO are studied thoroughly to check their individual influences on the objectives of the different actors, as well as on the SPI. This study is first conducted in a MAS where actors do not act for improving their SPI, and second taking into account SPI in their choices.

These studies showed the effectiveness of the multi-agent system to model such a complex interplay, and the main drivers that are actually making a change for the objective of each actor. For instance, the funding distributed from funding agencies have an impact for researchers and research facilities, but less on companies, while the conversion rate has an impact on companies and less for researchers.

The developed tool and model are extensible, new actors can be modelled easily, and the behaviour of each actor can be adapted. This represents the main contribution of this thesis for future studies.

6.2. Perspectives

This work is the basis of further ongoing studies and provides a base for various development. It includes the result of a 3-years lasting EC-funded project and the research of 3 years. And it can only be considered to be the first step.

Further investigation will have to be done, as already denoted in Chapter 5.

In a larger scope, the main extensions of the work will be the following:

- Develop new versions of the SPI indicator: This will need more interaction with social science. While the formula developed seems to be adequate in terms of global representation of the sustainability of the actors, it does not distinguish enough between the different scenarios. More emphasize must probably put more on some aspects than others, and the weights used for calculating the SPI must be better understood.
- Include in the multi-agent-system the notion of locality and position. Indeed, an actor might be influenced differently based on its country for instance (different laws leads to different incentives) and on its surroundings. The influence for the moment of the location is not present in the MAS, and the neighbourhood is up to now related to a neighbourhood between agents through links coming from projects and collaborations.

Netlogo allows for taking into account the actual physical position of the agents to adapt the agent behaviour and vice-versa (meaning an agent can influence its location). A new actor could therefore be proposed to model the government that would influence the actors being physically in its country.

- In the same vein, an actor could be influence by the SPI value from its physical surrounding, given this value is propagated to the locations the agents are on. In the preliminary work described in Chapter 5, the SPI values influence the actors, but more has to be developed so that the actors actually try to optimize a bi-objective function (their primary objective, for instance the number of publications or the reputation, and their SPI value)
- Other actors could be included step by step in the model, starting from governments, business angels, standardization bodies and influential groups. Probably a trade-off will have to be taken in order not to complexify too much the model, since the resolution time might become too large for the model to be useful. Such simplification was for instance already done with the funding agencies that are not fully designed as agents but behave regularly in the MAS model.
- On the engineering part, some developments have to be conducted to improve the Netlogo model, and in particular to be able to derive different version of the model dedicated to a specific actor: For instance a version could exist for a funding agency, a separate one for a company, and so on, where the changing parameters might be different and the change in their behaviours restricted to themselves.

Publications

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Chapitres de livres :

• C. Herzog, L. Lefèvre, JM. Pierson. *Actors for Innovation in Green IT*. In ICT Innovations for Sustainability. Lorenz Hilty, Bernard Aebischer (Eds.), Springer, 3, p. 49-67, Vol. 310, Advances in Intelligent Systems and Computing, January 2015.

• C. Herzog, JM. Pierson, L. Lefèvre. Towards sustainability for large scale computing systems: Environmental, Economic and Standardization aspects. In Large-Scale Distributed Systems and Energy Efficiency: A holistic view. John Wiley and Sons, 10, May 2015.

Conferences :

• *Green IT for Innovation and Innovation for Green IT : The Virtuous Circle*, C.Herzog, L.Lefèvre, JM.Pierson, 10th IFIP TC 9 International Conference on Human Choice and Computers, HCC10 2012, Amsterdam, September 2012, M.D.Hercheui, D.Whitehouse, W.McIver Jr, J.Phahlamohlake (Eds) Springer, ISBN 978-3-642-33331-6

• *Link Between Academia and Industry for Green IT*. Christina Herzog, Jean-Marc Pierson, Laurent Lefèvre. ICT for Sustainability (ICT4S 2013), Zürich, Switzerland, 14/02/2013-16/02/2013, ETH Swiss Federal Institute of Technology, p. 259-264, February 2013, ISBN I978-3-906031-24-8

• *Green IT for Standardization Bodies, Initiatives and their relation to Green IT focused on the Data Centre Side*, Christina Herzog, Energy Efficiency in Large Scale Distributed Systems Conference, EE-LSDS 2013, 22-24 April 2013, Vienna, Austria, Springer LNCS, 2013, ISBN: 978-3-642-40516-7 (Print) 978-3-642-40517-4 (Online)

• *Towards Modelling the research in Green IT with Agents*. Christina Herzog, Jean-Marc Pierson, Laurent Lefèvre. 27th International Conference on Environmental Informatics for Environmental Protection, Sustainable Development and Risk Management, EnviroInfo 2013, Hamburg, Germany, September 2-4, 2013 (EnviroInfo 2013): p. 335-341

Atelier :

• *The Potential for Environmental Savings – Restrictions, Internal Standards and Approaches*, PhD Workshop, ICT4S Conference, Zürich, February 2013

Poster :

LINKING ACADEMIA AND INDUSTRY FOR A GREEN (IT) SOCIETY, Poster, ICT4S Conference, (Best Poster Award), Zürich, February 2013

Présentations invitées :

• Panelist in FutureCleanTechForum. Pillar : New technologies – discover the leading edges. Session : Impact on the deployment of renewable energy technologies, October, 2012

• Presentation at GreenDays in Luxembourg, January 2013.

• Presentation at North Eastern University, Shenyang, China, August 2013.

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